

1993

Lake level changes within the Yellagonga Regional Park: A historic perspective

Jennifer A. Hamann
Edith Cowan University

Follow this and additional works at: https://ro.ecu.edu.au/theses_hons



Part of the [Environmental Monitoring Commons](#), and the [Water Resource Management Commons](#)

Recommended Citation

Hamann, J. A. (1993). *Lake level changes within the Yellagonga Regional Park: A historic perspective*.
https://ro.ecu.edu.au/theses_hons/259

This Thesis is posted at Research Online.
https://ro.ecu.edu.au/theses_hons/259

Edith Cowan University

Copyright Warning

You may print or download ONE copy of this document for the purpose of your own research or study.

The University does not authorize you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site.

You are reminded of the following:

- Copyright owners are entitled to take legal action against persons who infringe their copyright.
- A reproduction of material that is protected by copyright may be a copyright infringement. Where the reproduction of such material is done without attribution of authorship, with false attribution of authorship or the authorship is treated in a derogatory manner, this may be a breach of the author's moral rights contained in Part IX of the Copyright Act 1968 (Cth).
- Courts have the power to impose a wide range of civil and criminal sanctions for infringement of copyright, infringement of moral rights and other offences under the Copyright Act 1968 (Cth). Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

**"LAKE LEVEL CHANGES
WITHIN THE YELLAGONA REGIONAL PARK
A HISTORIC PERSPECTIVE"**

BY

Jennifer Anne Hamann

**A Thesis Submitted in Partial Fulfilment of the
Requirements for the Award of**

**Degree of Bachelor of Arts with Honours
at the School of Social and Cultural Studies
Faculty of Arts, Edith Cowan University**

Date of Submission: *October 1992*

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

CONTENTS

	Page
ABSTRACT	1
DECLARATION	2
ACKNOWLEDGMENTS	3
LIST OF FIGURES	5
LIST OF PLATES	7
CHAPTER 1 : INTRODUCTION	8
1.1 Yellagonga Regional Park	8
1.2 Location and Definitions	12
1.3 The Wetland Issue	13
1.4 Rationale for and Aims of the Study	15
CHAPTER 2 : METHODOLOGY AND LITERATURE REVIEW	18
2.1 Design of the Study	18
2.2 Literature Review	24
2.3 Literature on Methodology	26
2.4 Literature on Previous Findings	28
2.5 Specific Studies Similar to the Current Study	30
CHAPTER 3 : PHYSICAL ENVIRONMENT OF THE STUDY AREA	31
3.1 Catchment Area	31
3.2 Climatic Conditions	42
3.3 Hydrological Conditions	43
3.4 Water Quality	53
3.5 Topography, Geology and Soils	55
3.6 Vegetation	60
CHAPTER 4 : RECONSTRUCTION OF LAKE LEVELS	64
4.1 Historical Records	64
4.2 Oral Histories	79
4.3 Aerial Photography	84

4.4 Seasonal Variations	85
4.5 Current Measurements	90
CHAPTER 5 : THE RELATIONSHIP OF LAKE LEVELS TO CLIMATIC DATA	93
5.1 Wanneroo Data verses Perth Data	93
5.2 Degree of Correlation between Lake Levels and Climatic Data - Short Term	94
5.3 Degree of Correlation Between Lake Levels and Climatic Data - Seasonal	96
5.4 Degree of Correlation Between Lake Levels and Climatic Data - Long Term Seasonal Variations	98
5.5 Conclusions on Water Level and Climatic Data Correlation	100
CHAPTER 6 : RELATIONSHIP BETWEEN LAKE LEVELS AND THE HISTORICAL DEVELOPMENT OF THE CATCHMENT	102
6.1 Prior to European Settlement	102
6.2 History of Settlement	104
6.4 Residential Development	108
6.5 Current Status	113
6.6 Summary of Land Use History	113
CHAPTER 7 : CONCLUSIONS	117
7.1 Summary of Findings	117
BIBLIOGRAPHY	122

ABSTRACT

The Yellagonga Regional Park is located approximately 20 km north of Perth and 6 km east of the coast, in the City of Wanneroo. The park is comprised of Lake Joondalup, Beenyup Swamp, Wallubuenup Swamp and Lake Goollelal, a largely directly-linked wetland system and their surrounds. The importance of wetlands within the Perth Metropolitan area is widely documented with only 20% of the pre-European settlement wetlands remaining. (Godfrey, 1988; Davis, 1988) By comparison wetlands in the Yellagonga Regional Park are relatively natural in their state. (LeProvost, 1987) The park is of significance due to its conservation value, providing a varied array of wetland habitats, plants and animals. It is also of great educational, scientific and cultural value.

A detailed management plan for the park is essential. One aspect of managing the park is current and anticipated water level fluctuations. This study compares recorded and reconstructed water level data for the two lakes within the park, Lake Goollelal and Lake Joondalup, with rainfall, evaporation and land-use data. The correlation between some of these variables more fully described the historical variations in water levels that have occurred. Apparent trends in evaporation and rainfall have been analysed. There is a need to more fully investigate the apparent changes in this data, in particular the increased correlations between the evaporation, rainfall and water level data following urbanisation.

Historical reconstructions and oral histories from long time Wanneroo residents provide an insight into previously unavailable information on water level changes.

DECLARATION

"I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text."

ACKNOWLEDGMENTS

The information and help offered by the following persons and departments is acknowledged with gratitude.

Australian Bureau of Statistics

Bureau of Meteorology, particularly

John Relf, Climate Officer

The City of Wanneroo, particularly

Bob Ruscoe, Land Information Systems Officer

Doug Pearson, Engineer

Department of Land Administration, for its sponsorship particularly

Kerry Smyth, Centre Manager Central Map Agency

Ian Bell, Central Map Agency

The Edith Cowan University, Yellagonga Research Team, particularly

Mark Bannister

Water Authority of Western Australia, particularly

Stuart Gee, Engineer

Jeff Kite, Environmental Officer

Special thanks to the Crisafulli family, Ned Crisafulli and Bill Duffy, for their time and help with oral histories.

Also special thanks to the Swain family for their time and effort which is greatly appreciated.

Thanks must go to my family for their tireless help, assistance and support without whom this would never have been completed.

Final thanks are extended to Dr. Hugo Bekle for his supervision and guidance.

LIST OF FIGURES

	Page
Figure 1 : The Yellagonga Regional Park	9
Figure 2 : Projected Population Figures	10
Figure 3 : Proposed Recreational Facilities	11
Figure 4 : Locality Plan: Study Area	12
Figure 5a : Locality Plan: Graduated Water Staff Lake Joondalup	22
Figure 5b : Locality Plan: Graduated Water Staff Lake Goollelal	23
Figure 6 : Catchment Area: Yellagonga Regional Park	32
Figure 7a : Outlets, Sumps and Basins	39
Figure 7b : Outlets, Sumps and Basins	40
Figure 8 : Perth Annual Evaporation	43
Figure 9 : The Hydrological Cycle	44
Figure 10 : The Gnangara Mound	46
Figure 11a : Bathymetric Map: Lake Joondalup North	48
Figure 11b : Bathymetric Map: Lake Joondalup South	49
Figure 12 : Bathymetric Map: Lake Goollelal	50
Figure 13 : Historical Map: 1933	51
Figure 14 : Post Hole Log	52
Figure 15 : Aerial Photograph: Study Area	61
Figure 16 : Original Plan: Swan 36	66
Figure 17 : Original Plan: Swan 39	67
Figure 18 : Original Plan: Swan 41	71
Figure 19 : Chauncey, 1842a, Field Book 14	73
Figure 20 : Historical Map: 1909	78
Figure 21 : Historical Water Levels	79

Figure 22 :	Long Term Water Level Variations: Lake Joondalup	86
Figure 23 :	Long Term Water Level Variations: Lake Goollelal	86
Figure 24 :	Long Term Water Level Variations with Overlay: Lake Joondalup	87
Figure 25 :	Long Term Water Level Variations with Overlay: Lake Goollelal	88
Figure 26 :	Minimum and Maximum Water Levels: Lake Joondalup	89
Figure 27 :	Minimum and Maximum Water Levels: Lake Goollelal	89
Figure 28 :	Water Level Lake Joondalup & Lake Goollelal Seasonal Variations	90
Figure 29 :	Water Level Lake Joondalup & Lake Goollelal 12-month Cycle	91
Figure 30 :	Graph of Water Level Reconstruction	92
Figure 31 :	Water Level & Climatic Data : Lake Joondalup	94
Figure 32 :	Water Level & Climatic Data : Lake Goollelal	95
Figure 33 :	Seasonal Variations : Lake Joondalup	96
Figure 34 :	Seasonal Variations : Lake Goollelal	97
Figure 35 :	Long Term Seasonal Variations : Lake Joondalup	98
Figure 36 :	Long Term Seasonal Variations : Lake Goollelal	99
Figure 37 :	Historical Relationship : Lake Joondalup	103
Figure 38 :	Historical Relationship : Lake Goollelal	103
Figure 39 :	Land Use 1942	106
Figure 40 :	Land Use 1965	107
Figure 41 :	Land Use 1973	109
Figure 42 :	Land Use 1983	110
Figure 43 :	Land Use 1992	112
Figure 44 :	Unsewered Residential Land East of Lake Joondalup	116

LIST OF PLATES

	Page
Plate 1 : Jetty viewed from Neil Hawkins Park (September 1992)	15
Plate 2 : Look-out viewed from track around North-West side of Lake Joondalup	16
Plate 3 : Graduated Water Staff Lake Joondalup (October 1992)	20
Plate 4 : Graduated Water Staff Lake Goollelal (October 1992)	21
Plate 5 : Outlet end of Toronto Place	33
Plate 6 : Outlet end of Ottawa Way	33
Plate 7 : View towards Lake Joondalup from Ottawa outlet	34
Plate 8 : Outlet on Scenic Drive	34
Plate 9 : Outlet end of Church Street	35
Plate 10 : Basin end of Church Street	35
Plate 11 : Drain to Lake Joondalup from basin end of Church Street	36
Plate 12 : Drain end of San Rosa Road on bank of Lake Joondalup	36
Plate 13 : Basin end of Ariti Avenue	37
Plate 14 : Sump on Edgewater Drive	37
Plate 15 : Outlet on Lake Goollelal Western Bank	38
Plate 16 : Limestone outcrop Western shore - Lake Joondalup	56
Plate 17 : Limestone outcrop Western shore - Lake Joondalup	57
Plate 18 : Eastern shore gently rising	58
Plate 19 : Eastern shore of Lake Joondalup (background)	58
Plate 20 : Western shore of Lake Joondalup (background)	59
Plate 21 : Western shore rising sharply	60
Plate 22 : Vegetation zones of Yellagonga Regional Park	62
Plate 23 : Water running into drainage channel	80
Plate 24 : Submerged Fence Posts : Southern end Lake Joondalup	81

CHAPTER 1 : INTRODUCTION

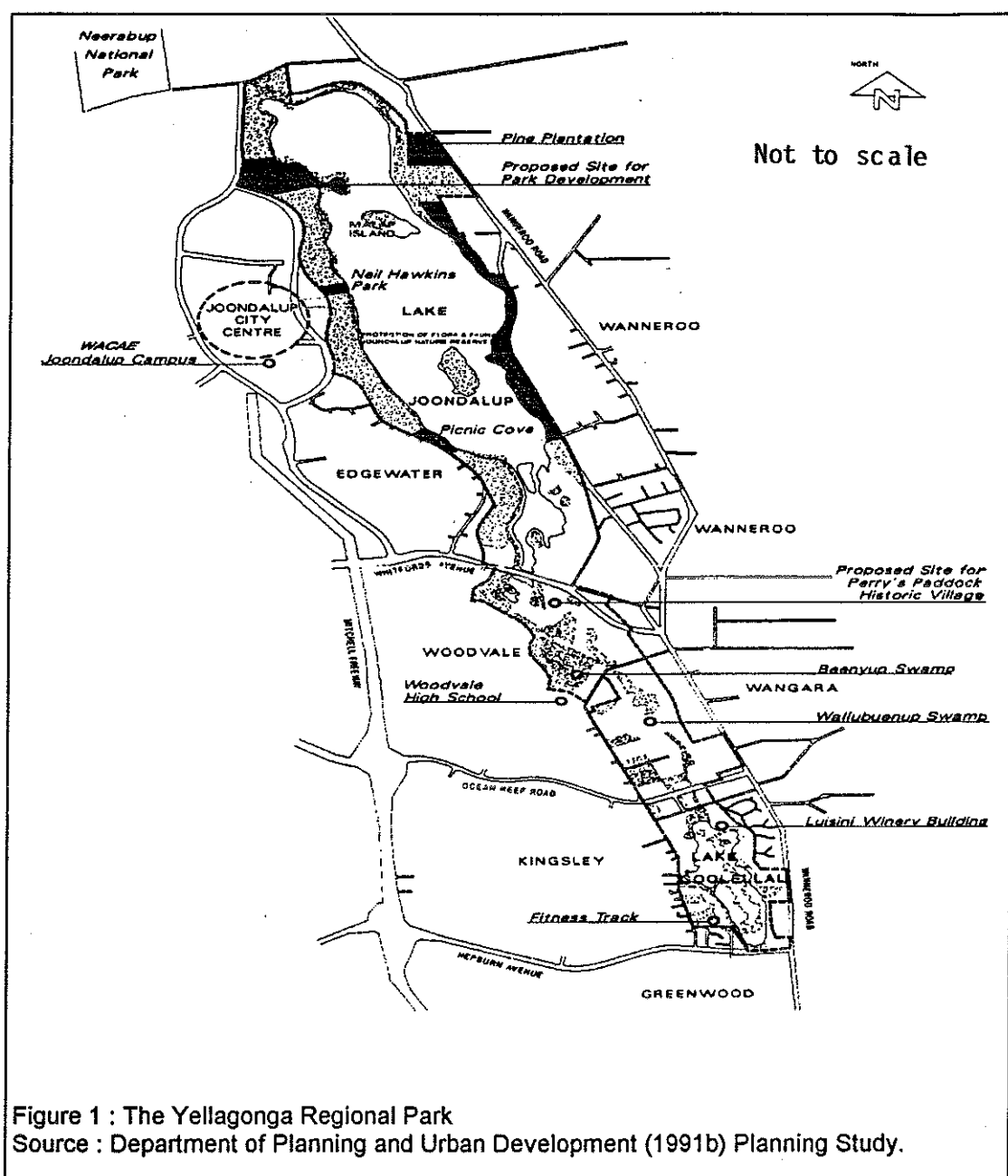
1.1 Yellagonga Regional Park

The Yellagonga Regional Park is comprised of Lake Joondalup, Beenyup Swamp, Wallubuenup Swamp and Lake Goollelal, a large directly-linked wetland system and its surrounds. Lake Goollelal is approximately 10m higher than Lake Joondalup. Water drains from Lake Goollelal into Wallubuenup Swamp via culverts under Hocking Road and Whitfords Avenue then into Beenyup Swamp which is connected by a stream to the southern tip of Lake Joondalup. The main body of Lake Joondalup is cut off from the southern tip by Ocean Reef Road and is only connected by a drain under the road during the winter months when the water rises to the level of the culvert.

The boundaries of the park have been set by the Department of Planning and Urban Development following extensive assessment, of the System 6 proposal, ecological and park management considerations, and evaluation of acquisition costs. The park encompasses an area of approximately 1,400 hectares. See *Figure 1, p.9*. Owing to the huge acquisition cost, due to much of the land being in private tenure, all land inside the road boundaries has not been included. Within the wetland catchment land use on private property and other areas outside the park boundary will be significant, as these will all, to some extent, impact on the water levels of the individual wetlands.

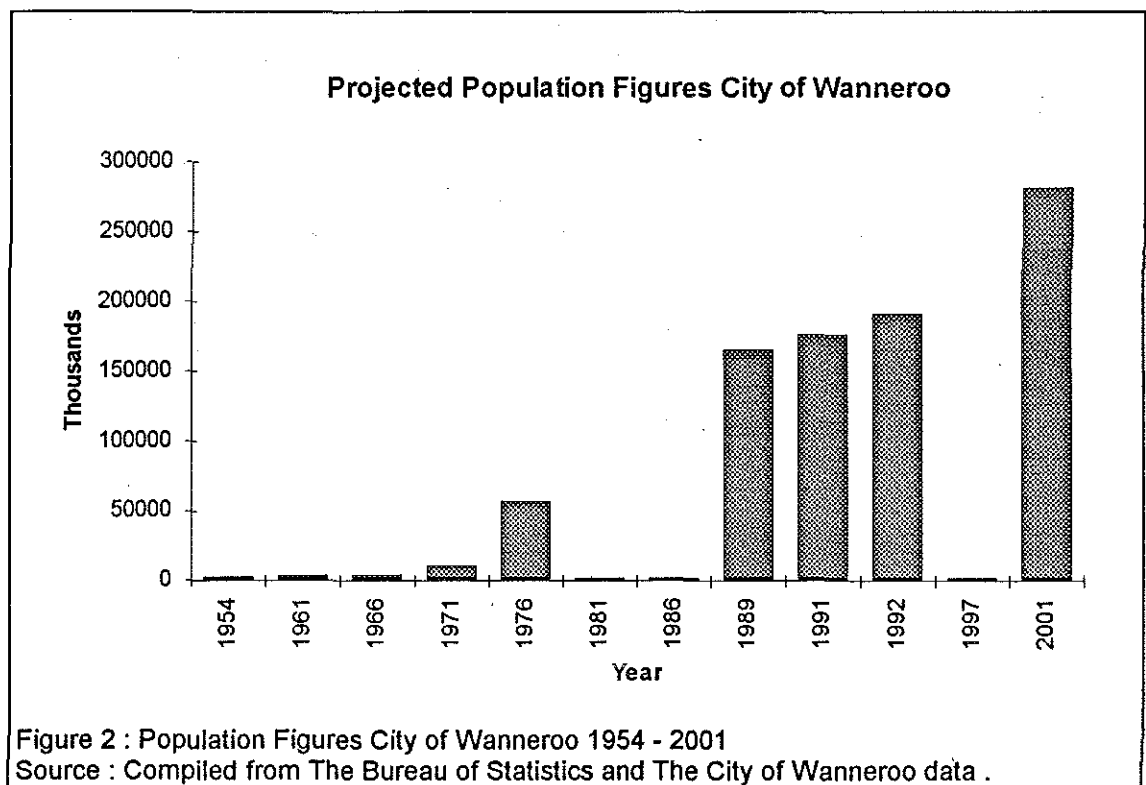
The wetland systems have undergone many changes due to the impact of varying land use since European settlement of the area in 1837. These effects have continued to escalate over time and currently the wetland system is under increasing pressure arising from the conflict of interest amongst competing land use groups who wish to utilise the water and land resources of the Yellagonga Regional Park. Added to this is the use of the ground water resources of the

Gnangara Mound which also has the potential to impact on the wetland system.
(Dames & Moore, 1986a)



The City of Wanneroo's population increased from 2,437 in 1966 to 55,328 in 1976, in June 1989 it was 163,722, and in June 1992 it had grown to 189,370. It is currently the fastest growing city in Western Australia, a growth that it has sustained over the past twenty (20) years. The projected population figure for the year 2000 is approximately 280,000, representing a 50% increase in the

current population. (Planning Department, City of Wanneroo, 1991 & 1992, pers. com.) See Figure 2.



The statistics show that much of this increased population comes from young families entering the area. (A.B.S., 1990, pers. comm.) This increase in population will have a twofold effect. Additional housing will be needed which will necessitate the clearing of vegetation. This will have an affect on the water level of the lake system, through increased run-off and decreased evapo-transpiration. There will also be increased pressure on, and demand for, recreational facilities within the Yellagonga Regional Park. A variety of additional passive recreation facilities similar to Neil Hawkins Park are already proposed, see Figure 3, p.11. These facilities once provided will reduce the area of natural vegetation and increase paved and grassed areas. This will also cause increased run-off and decreased evapo-transpiration, which in turn is likely to alter the water balance and therefore the lake levels. It is, therefore, necessary to establish base line data of historical changes in water levels, to provide for future management and monitoring of these wetlands.

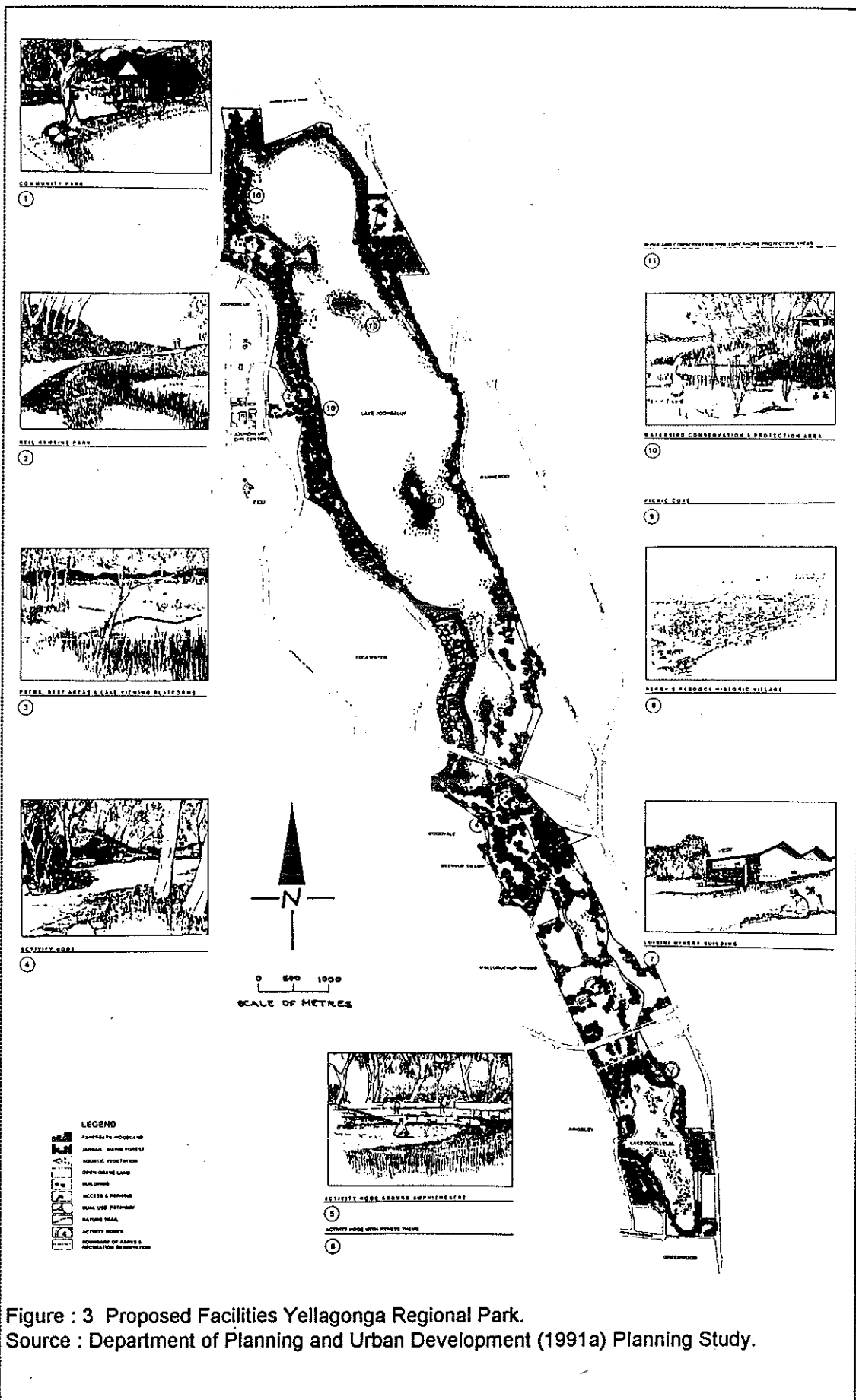


Figure : 3 Proposed Facilities Yellagonga Regional Park.
 Source : Department of Planning and Urban Development (1991a) Planning Study.

1.2 Location and Definitions

The wetland system is located approximately 20km north of Perth and 6km east of the coast, in the City of Wanneroo, which comprises part of the North-West Corridor of the Perth Metropolitan Region. See Figure 4.

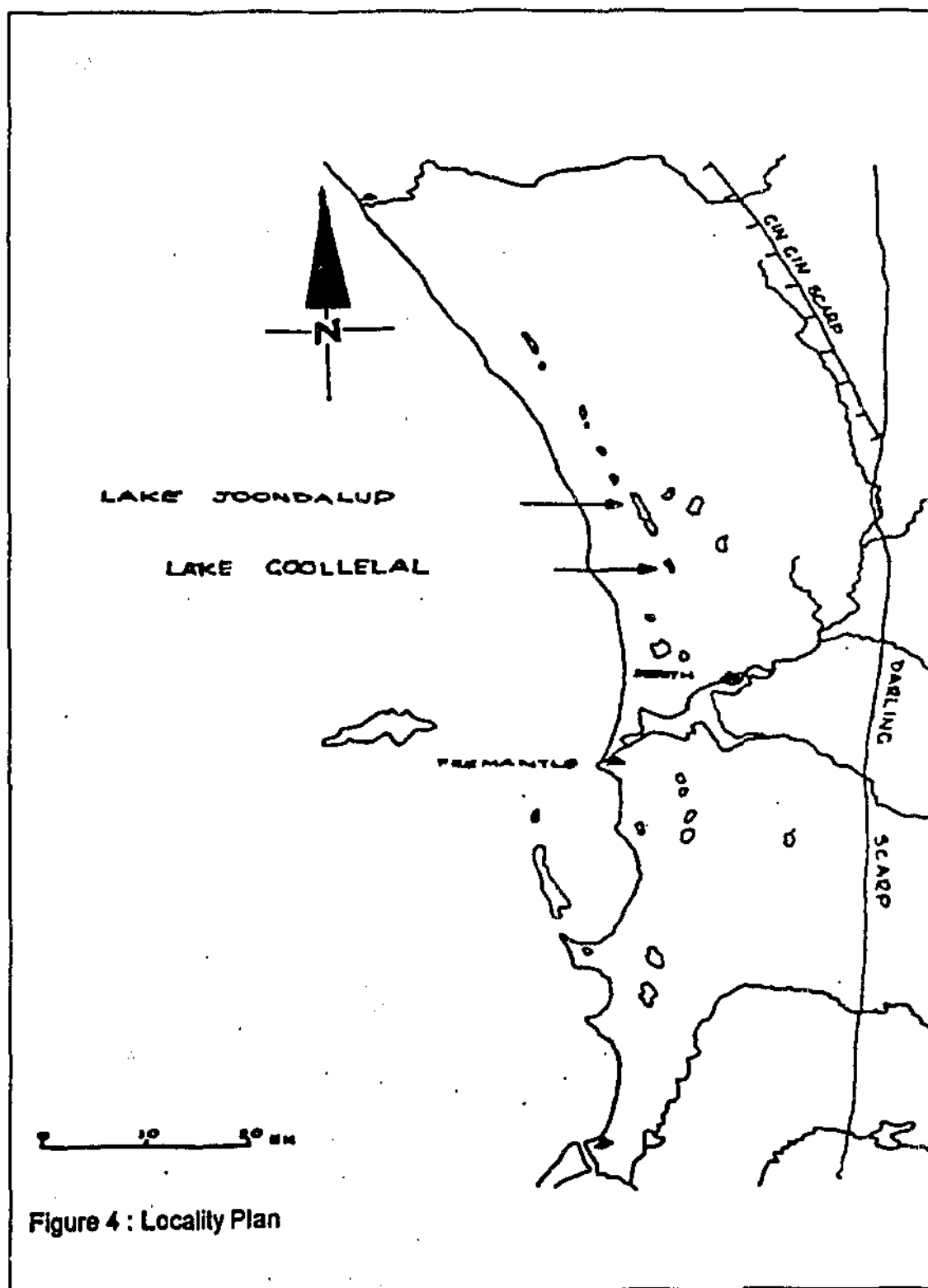


Figure 4 : Locality Plan

The wetland system is located in an inter-dunal depression and is part of the chain of lakes extending from Lake McNess to the north, and ending at Lake Goollelal at the southern most point. These lakes are linear in shape, steep sided and relatively permanent. They lie parallel to the coast and are surface expressions of the Gnangara Mound Ground-water. They fall within the coastal limestone belt of the Swan Coastal Plain. (Allen, 1976, p.122)

Wetlands in the South-West of Western Australia are generally characterised as "seasonally, intermittent or permanently waterlogged soil or inundated land; whether natural or otherwise, fresh or saline, eg. waterlogged soils, estuaries, rivers and their tributaries". (Wetlands Advisory Committee, 1977)

1.3 The Wetland Issue

Wetlands throughout Western Australia are being studied in great detail as is evident by the proliferation of literature currently being produced. This is due to the loss of approximately 80% of Western Australian wetlands since European settlement. Wetlands have been lost through their use as sanitary landfill sites, for disposal of industrial and inert waste and their drainage and filling for agriculture and urban development. These losses compound the importance of the existing chain of wetlands, within the Yellagonga Regional Park.

The Yellagonga Regional Park is of enormous conservation value. It is an area of high biological productivity that helps to support a varied array of wetland habitats, plants and animals. The wetlands attract migratory wading birds from the northern hemisphere as well as birds displaced from shallow inland wetlands, migrating to the coast as wetlands dry out during the summer. This makes it of great educational, scientific and cultural value. (Bekle, 1988, p.3; Davis, 1988, p.52; Godfrey, 1988, p.5)

Much of Perth's water supply comes from the Gnangara Mound ground-water source. In March 1988, the Minister for the Environment imposed minimum water level conditions for the wetlands of the Gnangara Mound. These minimum levels, although enforced for the protection of the wetlands restrict the natural fluctuations in lake levels which provide habitat diversity, including seasonally exposed mudflats. (Western Australian Water Resource Council, 1988)

The wetland flora and fauna of the Yellagonga Regional Park are naturally adapted to quite dramatic seasonal fluctuations in water levels and are sufficiently resilient to recover from seasonal variations and prolonged drought. A permanent change in water level is, however, likely to cause permanent change in the wetlands and their biota. It is, therefore, necessary to have a network of sites of different types to assure the resilience of the ecosystem as a whole. Of particular importance is the shallow littoral zone as it is the most productive zone of the lake for aquatic life. (Bekle, 1984, p.74; Dames & Moore, 1986, p.69)

This study will contribute to the current pool of knowledge on these seasonal changes as well as providing long term data on water level changes. Therefore, when managing authorities review these minimum and maximum water levels in the future, a more detailed knowledge of the lake systems' natural seasonal and long term cycles will be available.

The Yellagonga Regional Park also has economic value. Real estate prices tend to be higher adjacent to wetlands. Recently developers have utilised the aesthetic qualities of wetlands as attractive selling points, eg. Edgewater on the south side of Lake Joondalup. It is this author's opinion that these wetlands will be put under further pressure due to their proximity to the Joondalup City Development and its related expanding residential areas.

1.4 Rationale for and Aims of the Study

An integral part of the water balance of these lakes is seasonal variation. Each year the lakes experience significant changes in depth, and hence in area, during the seasonal transformation from high water to low water. These changes also vary in magnitude from one year to the next, according to climatic conditions. Future management of the Yellagonga Regional Park requires extensive investigation of this and other related issues. As Bekle (1988, p.9) referring to wetlands in Western Australia, states "detailed baseline studies are urgently required to establish the criteria on which future management and monitoring of changes might be based." The aim of this study is to provide base line data on water levels of the lakes in the Yellagonga Regional Park. *Plates 1 & 2* demonstrate the need for comprehensive water level data.



Plate 1 : Jetty viewed from Neil Hawkins Park (September 1992) The jetty is completely submerged making it unusable. Comprehensive knowledge of past water levels would have allowed planners to build the jetty at a height that would avoid flooding and allow year round use.



Plate 2 : Look-out viewed from track around North-West side of Lake Joondalup. The track on both sides of the lookout is flooded making it difficult to reach and use. Information provided by this study will assist managing bodies in appropriately positioning built structures to avoid flooding.

Due to insufficient information these built structures have been submerged by the rising water levels leaving them unusable.

The aim of this study is to reconstruct the water level changes of the wetland system contained within the Yellagonga Regional Park. A correlation was made between lake water levels and climatic data cognisant of historical land-use activity within the catchment. It is proposed that climatic data coupled with the land-use history of the catchment will help to explain the long term variations in lake levels.

It is therefore hypothesised that long term lake level variations can be adequately explained using climatic data coupled with knowledge of the land-use history of the catchment.

A thorough examination of changing water levels of the wetlands of the Yellagonga Regional Park related to climatic conditions and land-use activities, within the catchment, will contribute to the existing data base necessary for the effective future management of water levels.

This study could also provide invaluable baseline data for a range of current research projects being conducted on the wetland system, by Edith Cowan University and through the sponsorship of the Western Australian Water Authority. The quantity of water in the system affects all aspects of the wetlands from water quality to the fringing vegetation and, it is postulated, that linkage exists with climate and land-use.

The study will encompass the following four (4) aspects.

- (a) To reconstruct the water level changes of the lake systems, both seasonal and long term.
- (b) To test the relationship between lake levels and climatic records.
- (c) To contribute current data on rainfall, evaporation and lake levels through field measurements and observation.
- (d) To test possible relationships between changing water level and changing land-use within the catchment.

CHAPTER 2 : METHODOLOGY AND LITERATURE REVIEW

2.1 Design of the Study

This research project was conducted from February 1992 to October 1992.

The project incorporates two (2) major components, historical and physical, which have been evaluated qualitatively and quantitatively.

The qualitative study deals with a historical reconstruction of water levels of Lake Joondalup and Lake Goollelal. This entails four distinct means of data collection.

The first of these was the reconstruction of water level changes through historical documents which has provided anecdotal observations, giving some insight into water levels from the period prior to 1900. This was done using maps in conjunction with surveyors' diaries, the diaries and correspondence of settlers, boundary descriptions from land grants and newspaper reports. Due to the paucity of information available on Beenyup and Wallubuenup Swamps this study concentrates on Lakes Joondalup and Goollelal.

The second source was oral histories, which were originated for the purpose of this study. Long term residents were interviewed and relevant information was used to provide data between early written records and Western Australian Water Authority records. Information provided was compared with available written documents, maps and climatic records in order to substantiate the data.

The third method examined aerial photography. Records commenced in 1942 and with the use of magnification, a planimeter, and current aerial photographs with known water levels, an approximate water level was obtained from aerial photographs taken between 1942 and 1953.

Finally, water level information supplied by the Western Australian Water Authority was used. Monitoring of the water levels began in 1951 for Lake Goollelal and 1954 for Lake Joondalup. Original measures were sporadic. Monthly readings commenced for Lake Joondalup in 1970 and for Lake Goollelal in 1978.

Climatic data, on rainfall and evaporation, was obtained from the Bureau of Meteorology. The Bureau has only been in existence since 1968 and no evaporation records using a Class "A" Pan are available prior to this.

Evaporation records are available from 1953 to 1968 using a standard tank, from 1899 to 1953 using a square slate with annulus and 1876 to 1899 using an evaporation dish. Rainfall data was kept by the Lands and Survey Department from 1876. Due to the complexity of using the many different evaporation measures and the lack of consistency in measurements, the study concentrates on rainfall when comparing lake levels to climatic data.

Evaporation data was, however, still collected and used in conjunction with the more recent Class "A" Pan Evaporation figures.

This completed the historical aspect of the water level reconstruction.

Physical parameters were approached in a quantitative manner. The mapping of the catchment area was undertaken using both topographic and orthophoto maps provided by the Department of Land Administration. The peaks surrounding the wetland system were located, the boundary was found by following the ridges and contours and joining these peaks. The drainage systems within the catchment area were then mapped using tax sheets. These were provided by the Engineering Department of the City of Wanneroo, together with arterial drainage information system maps from the Western Australian Water Authority. There were gaps in the information available as many plans were proposals for drainage rather than drainage actually installed.

Therefore, the information was checked through site inspection to ensure that these plans were initiated and to find any additional outlets, sumps and basins not recorded. The park boundaries were overlaid to give a visual indication of the great difference between the park and catchment boundaries. This defined the area of study and highlighted the impact of drains, showing them as possible sources of additional water to the wetland system.

The collection and synthesis of existing information on the Yellagonga Regional Park area was undertaken to provide an overview of the different physical parameters that affect the water level within the wetland system.

The recording of current measurements of lake levels, rainfall and evaporation was undertaken. Climatic data was recorded daily at 9.00 am in accordance with recommendation by the Bureau of Meteorology. Lake water levels were taken from graduated water staffs located at Lake Goollelal and Lake Joondalup, see *Figures 5a and 5b, p.22-23 and Plates 3 and 4, p20-21*



Plate 3 : Graduated Water Staff Lake Joondalup (October 1992) Note the high water level which produces a large expanse of open water, when the water level is this high many of the shallow habitats are missing, eg no exposed mudflats.

Records were initially taken weekly from Lake Goollelal at 8.30 am and Lake Joondalup at 9.30 am . In September the water levels began to rise rapidly, reaching almost record highs, therefore daily monitoring of water levels was undertaken.



Plate 4 : Graduated Water Staff Lake Goollelal (October 1992) Surrounding reeds made it necessary for water levels to be taken by wading out and reading the water staff from a clearer position. A line has previously been cut through the reeds to allow for better access to the staff.

The limited time frame of the study impacted on this section of the research, as measurements were restricted to the winter months. This had the affect of maximising rainfall affects and minimising evaporation on newly collected data. Synthesis of existing and collected data was undertaken in order to establish both the seasonal and long term variation in the lake levels. A correlation between lake levels and climatic conditions was then undertaken. The base line data collected was correlated with data obtained from the Bureau of Meteorology and other studies, to help establish a better understanding of the hydrology of the wetland system and the changes that have and are occurring.

Scale : 1:5000

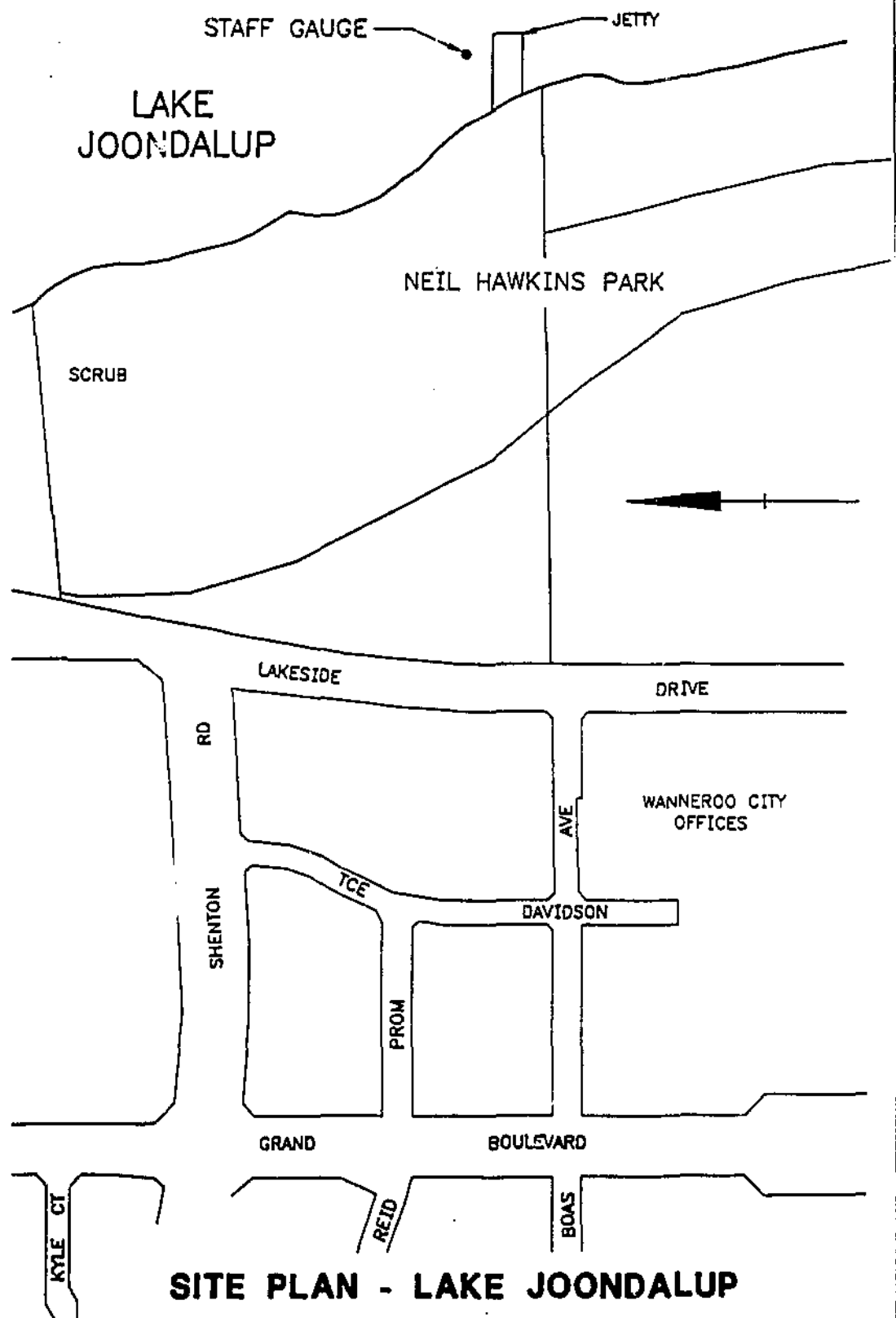
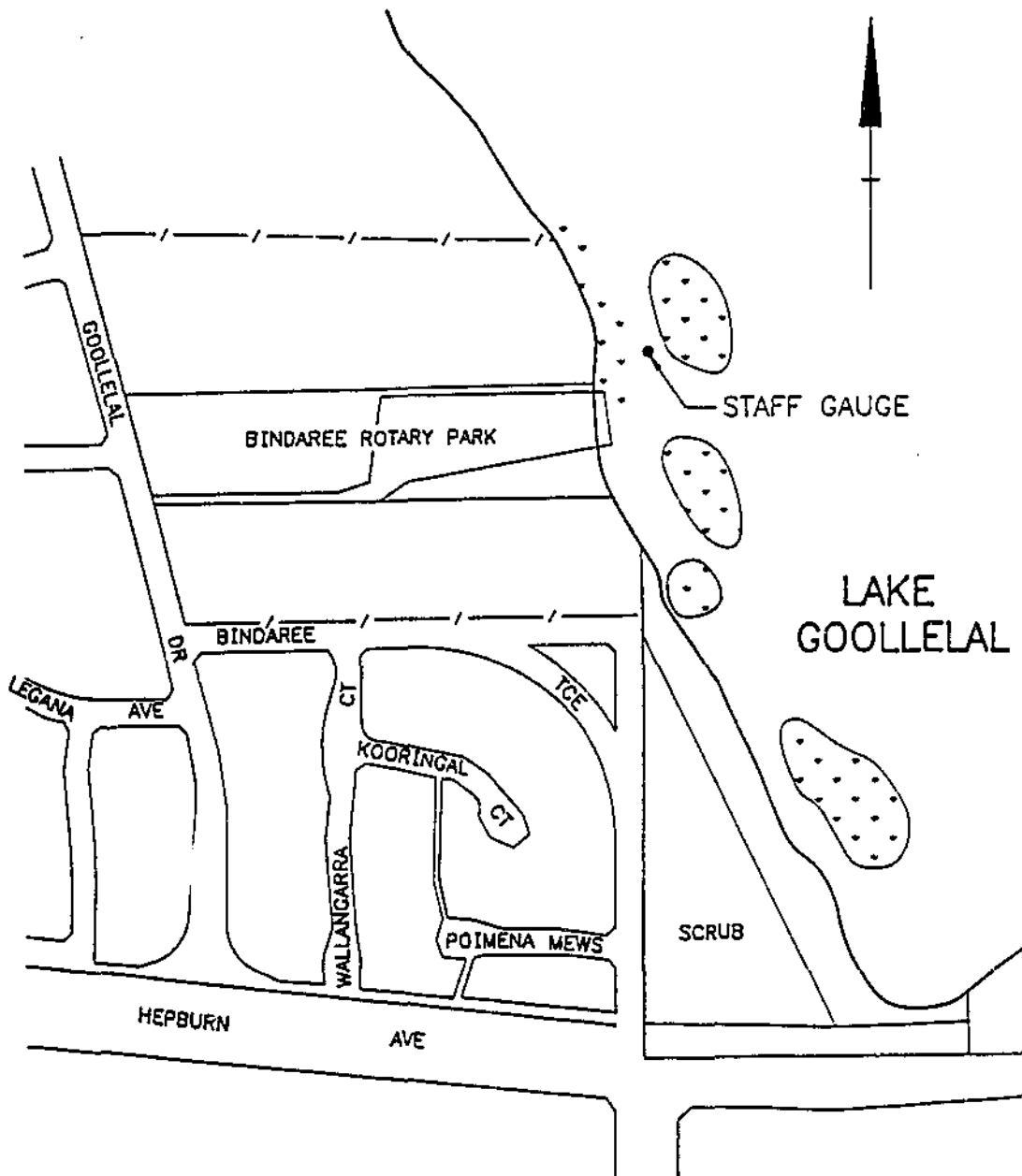


Figure 5a : Locality Plan of Graduated Water Staff Lake Joondalup

Scale : 1:5000



SITE PLAN - LAKE GOOLLELAL

Figure 5b : Locality Plan of Graduated Staff Lake Goollelal

A study of historical land-uses within the catchment area was utilised together with field observations of current land-use in order to provide a more complete picture of water level changes. The data is used to suggest possible links between changing water levels and land-use history.

In conclusion the study attempts to address the relevance of the findings to current management plans, particularly in relation to future maintenance of water levels.

2.2 Literature Review

As with many aspects of the environment, interest in the study of wetlands has only developed over the past two decades. Prior to this there had been little or no documentation of the natural and aesthetic qualities of wetlands.

In recent years there has been an upsurge in interest, understanding and concern for wetlands, both scientific and commercial. An increased awareness of the potential for sought after residential developments, adjacent to wetlands, coupled with the awareness of the value of the diversity and uniqueness of many plants and animals in wetlands, has led to a rapid increase in literature exploring opportunities to protect wetlands.

The bulk of this literature refers to wetlands in general, exploring common aspects associated with wetlands. The remainder explores specific wetland systems, defining issues of particular significance to a particular wetland, such as water level changes, and their affect on the wetland.

The Environmental Protection Authority, in June 1988, held a wetland conference. The subsequent publication "Wetlands in Crisis : What Can Local Government do?" deals with all issues facing wetlands.

Two (2) of the contributions to this study are reviewed below as they refer directly to water levels of wetlands and therefore are of importance to this study.

Davis & Humphries (1988) stress the importance of ground-water as a water resource in the Perth region and the value of wetlands, a part of this resource. The authors describe the link between water levels and the region's Mediterranean climate with cool wet winters and hot dry summers. The wetlands, they find, experience a strong seasonal hydrological cycle. Increased water levels in winter due to recharge from rainfall and decreased in summer as the wetlands act as evaporation basins.

The affects of urbanisation on wetlands is examined by Davis & Humphries (1988). Many act as compensating basins within local drainage systems and as a consequence receive a considerably greater proportion of their water from surface inputs than they did in the past, resulting in increased water level. Others have been affected by over pumping of the ground-water for domestic and horticultural water supply, leaving them in danger of having too little water to sustain aquatic life.

Davis & Humphries (1988) conclude that too much or too little water disrupts wetland ecosystems and that, due to their shallowness, long term changes in watertable elevation from the normal seasonal variations may present a serious threat to wetland ecosystems.

This paper highlights the importance of the natural water balance being maintained. The Yellagonga Regional Park had not been analysed as to whether the changing water levels are due to the natural fluctuation of wetlands, due to the disturbance of urbanisation or a combination of the two. This thesis seeks to evaluate these differing scenarios, established by Davis and Humphries, in the context of the Yellagonga Regional Park.

The primary objectives of the Water Authority are outlined by Ventriss (1988) as provision of services and management of water resources, with a number of supporting objectives including environmental considerations.

Ventriss (1988) suggests that, maintaining acceptable wetland water levels is the major determinant in setting the availability of the ground-water for public and private use and that existing criteria for the protection of wetlands are fairly rudimentary. He concludes that there is a real challenge to develop better water level and quality criteria which more effectively protect the valued attributes of wetlands. This thesis endeavours to provide a better understanding of the water level changes within the Yellagonga Regional Park and to establish the importance of these naturally occurring or man made fluctuations.

2.3 Literature on Methodology

Atkins & Humphries (1988) in *Wetlands in Crisis* indicate the importance of defining the wetland's catchment, its drainage channels, and the land-use within the catchment, and declare that any change in the amount or quality of water going in or out will alter the system. Hence the importance of the catchment and drainage map for the Yellagonga Regional Park forming part of this thesis. A clearly defined catchment boundary will be essential to policy makers in providing a management plan for the Park.

Congdon (1985) studied rainfall, ground-water and evaporation to determine the volume of water transferred into Lake Joondalup. Congdon (1985, p.1) gives the water balance equation as:

$$\Delta S = Si + P \pm GW - E \text{ or } \pm GW = \Delta S - P - Si + E$$

Where ΔS = change in surface water storage

Si = surface water inflow

P = precipitation

$\pm GW$ = net ground-water exchange

E = evaporation

Congdon explains that due to the difficulty and expense of measuring ground-water inflow and outflow, net ground-water exchange was estimated as the residual in the water balance equation. This assumes a state of essential equilibrium but includes inflow to Lake Joondalup from the adjacent wetlands Beenyup and Wallubuenup Swamps and Lake Goollelal.

Congdon measured changes in water level and lake volume using graduated staffs and a bathymetric map from the Water Authority of Western Australia. Depth measurements were taken twice weekly along with rainfall and evaporation measurements. Rainfall input was calculated by multiplying rainfall records for each 28-day period by the average area of the lake for the period. Lake evaporation was measured by multiplying pan evaporation by a pan factor (lake to pan coefficient) for each sampling period and then multiplying by the average area of the lake for that period.

Congdon (1985) documents water level changes in the lake as following seasonal patterns of low levels during April - May, and high levels during September-October. He also concluded that lake levels have been lower and more erratic in the past, as is evident from the submerged fence posts in the southern end of the lake and on the western side of Malap Island and from early aerial photographs. Congdon (1985) suggests clearing of native bushland decreased evapo-transpiration and interception, increased run-off from roads and rooftops which concentrates rainfall, and imported scheme water from septic tanks and irrigation as possible causes for increased lake levels.

This thesis aims to describe the historical changes in water levels, and expand on the base line data collected by earlier studies (eg Congdon). Unlike Congdon's model of the water balance this study will concentrate only on water level changes. Calculations of lake volume is beyond the scope of this study, although the data produced by this research could be utilised for this purpose.

2.4 Literature on Previous Findings

Dames & Moore (1986a) identify rainfall as the most important climatic factor as it is the only source of recharge to the Gwangara Mound. Dames & Moore, (1986a) find that urbanisation changes the water balance by affecting recharge and run-off characteristics. There is increased run-off into drainage sumps and other holding structures. The introduction of private wells for garden watering also affects this balance.

This thesis looks closely at the relationship between rainfall and the water level of the wetlands within the Yellagonga Regional Park. It also investigates the extent of additional drainage into the system through urbanisation of the catchment area.

Gerritse, Barber & Adeney (1990) compare both quantity and quality of discharges. The authors have presented their findings on recharge to the ground-water table through recently developed and established, sewered and unsewered areas. This study utilises their findings to approximate the additional water entering the system through the unsewered areas within the catchment.

Davis & Rolls (1987) demonstrate that lowered water levels alone may not adversely affect wetlands. Instead they suggest that seasonal drying of wetlands may be beneficial, by reducing nutrient cycling and habitat to fauna at the time of poorest water quality. Conversely, the authors also suggest that the affects of evaporation and low water levels may lead to unacceptable increases in salinity and nutrient levels. Davis & Rolls (1987) find that there is significant variation between individual wetlands. Water levels should be evaluated on an individual basis and not simply have a blanket figure applied. On the basis of this proposition an attempt to describe the natural fluctuations of the lakes of the Yellagonga Regional Park wetlands has been made. These fluctuations, even prior to urbanisation of the catchment extend beyond the range of the currently imposed minimum and maximum.

Bekle (1984) presents a comparative view of lakes in the Perth metropolitan area. He states that lake water levels vary following the Perth water balance, (rainfall minus evaporation) in the previous three months. Also that the monthly climatic water balance may vary considerably, whereas the water levels in lakes varies more slowly due to the influence of ground-water. (p.66)

Bekle (1984) quotes Southern & Teakle (1937) who suggest that water levels of the Perth Metropolitan area began to rise in 1910. He suggests this trend stopped in the 1970s due to a series of years experiencing exceptionally low rainfall and high evaporation, and altered again in the early 1980s with the

onset of high rainfall. Bekle (1984) proposes that due to the shallowness of the lakes, enormous differences in some lake areas may result as levels fluctuate. The author concludes that small vertical fluctuations in water level can produce considerable changes in depth profile and in surface area of the shallower lakes. Therefore falling levels in summer cause shorelines to retreat rapidly exposing bare mudflats.

Bekle (1984) explains the necessity of these lake level variations. They provide a wide array of habitats for the wildlife that feed, nest and roost there. This further confirms the importance of chronologically demonstrating the fluctuations for the Yellagonga Regional Park wetlands.

2.5 Specific Studies Similar to the Current Study

Evans & Sherlock (1950) have reconstructed the water level of Butler's Swamp, now Lake Claremont. The authors used an assortment of techniques including annotative information from diaries, early maps and photographs, interviews with local residents, records of data on water heights above low water at Fremantle and several swamps and wells in the metropolitan area.

Evans & Sherlock (1950) conclude that water table variation correlates to the amount of rainfall received and that the change from a swamp to a lake, that Butler Swamp underwent, shows that such very important changes in the natural environment may take place in a period of a few years. Therefore human impacts may not be necessary to explain the rapid changes.

This study endeavours to evaluate the degree of natural fluctuation, if any, caused by human impact for the Yellagonga Regional Park wetlands.

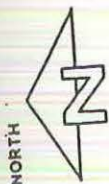
CHAPTER 3 : PHYSICAL ENVIRONMENT OF THE STUDY AREA

3.1 Catchment Area

The catchment area of the Yellagonga Regional Park is very large in comparison with the surface area of the water bodies. It consists of a total area of 5065 hectares. *See Figure 6, p.32.* This area is currently not completely developed. All areas however have been zoned under the provisions of the City of Wanneroo, Town Planning Scheme No. 1. Currently 2808 hectares is zoned urban of which 1525 hectares remains undeveloped, 316 hectares is zoned commercial/light industrial of which 145 is presently undeveloped. The remaining 1941 hectares is zoned Open Space. The land area is approximately 1200 hectares and the lake area is approximately 740 hectares of which Lake Joondalup represents 529 hectares, Lake Goollelal 122 hectares, Wallubuenup Swamp 49 hectares and Beenyup Swamp 40 hectares. (These area measurements were calculated with the aid of a planimeter.)

Throughout the catchment there already exists an established storm-water drainage system. The extent of this system was uncovered through the examination of tax sheets provided by the City of Wanneroo. Field research was also conducted as the City of Wanneroo records are incomplete. It was discovered that there are 8 outlets, discharging directly into the lakes, and 17 sumps and 2 basins in the surrounding area of the catchment.

See Figure 7a & 7b, p.39-40 Plates 5-15, p.33-38



Scale : 1:50,000

Figure 6 : Catchment Area; Yellagonga Regional Park
Source : Compiled from Topographic Survey Muchea SW and Perth NW.



Plate 5 : Outlet end of Toronto Place : Drainage pipe emptying into reserve adjacent to north eastern bank of Lake Joondalup. One of seven outlets discharging into Lake Joondalup on the eastern bank.



Plate 6 : Outlet end of Ottawa Way : Drainage Pipe Discharging into Channel leading to Lake Joondalup. Road runoff is collected from the surrounding area and discharged without any treatment through this and other outlets into the lake.



Plate 7 : View of drainage channel leading to Lake Joondalup from the Ottawa outlet. Note the proximity of the drain to the lake which can be seen behind the fringing vegetation of sedge, *Baumea articulata* and paperbark, *Melaleuca raphiophylla*.



Plate 8 : Outlet on Scenic Drive : Note accumulation of thick bloom of blue green algae, *Anabaena spiroides*, indicative of nutrient run-off. Possible sources are garden fertilizer and faecal contamination.



Plate 9 : Outlet pipe end of Church Street feeding into basin : Note the high water level with only the upper rim of the pipe showing. Also the debris which is collected and discharged with the water thereby polluting the area.



Plate 10 : Basin end of Church Street : Note the dumping of rubbish and the invasion of exotics. The reeds in this basin would assist in the removal of some of the nutrients enriching the water channeled into this basin before it reaches the lake.



Plate 11 : Drain to Lake Joondalup from basin end of Church Street. This drain carries water and debris collected in the basin from the roads and discharges it directly into the lake.



Plate 12 :Basin, end of San Rosa Road on bank of Lake Joondalup : This clearly shows the close proximity of the basin to the body of the lake. The groundwater flow would carry this water and its added nutrient load directly into the lake body.



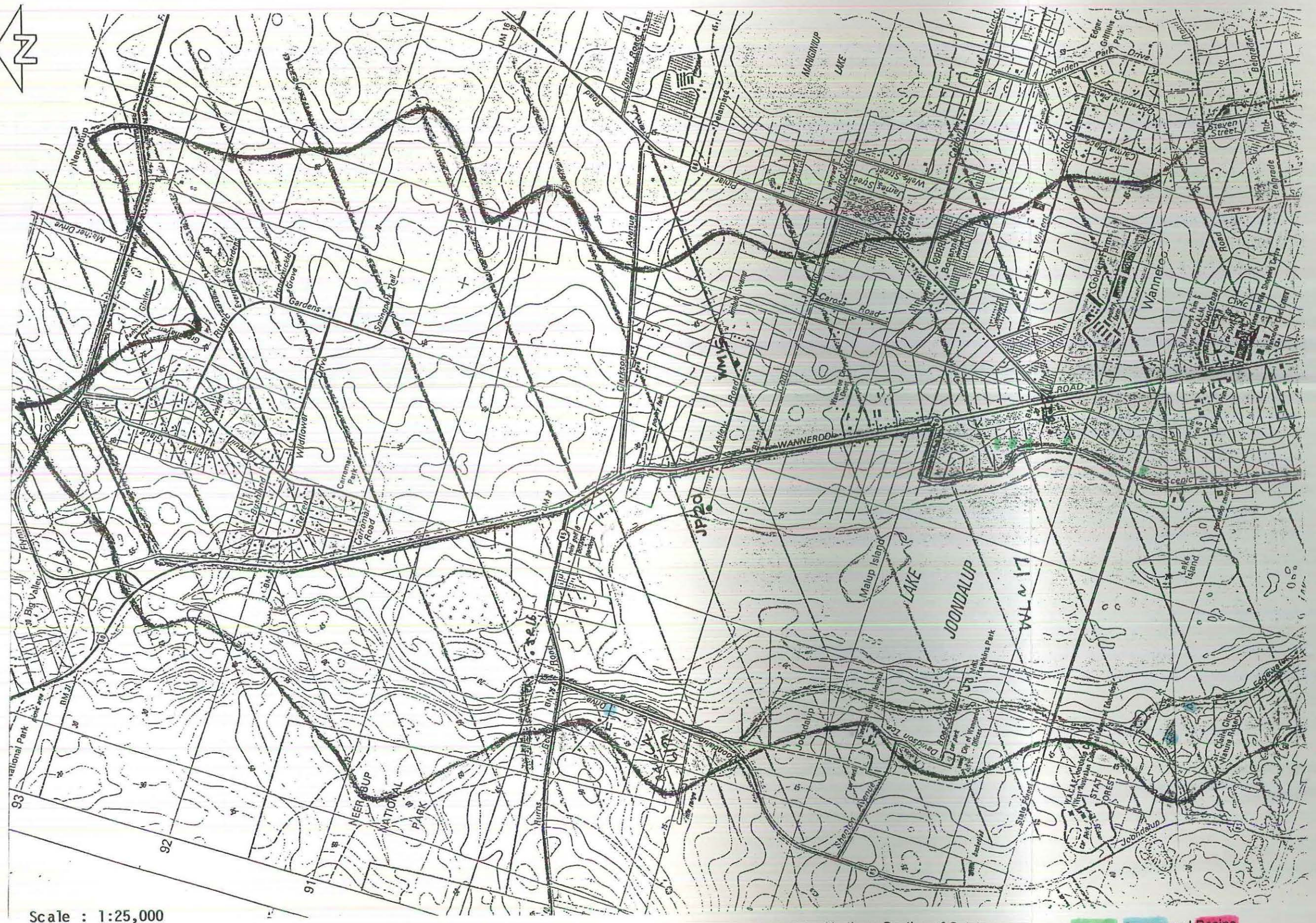
Plate 13 : Basin on Ariti Avenue : This artificial lake is used as a drainage basin for stormwater run-off. The groundwater moves in a westerly direction eventually contributing to the water level of the lake.



Plate 14 : Sump on Edgewater Drive : One of the many sumps in the catchment area. Water collected in these sumps rapidly drains through the porous soil contributing to the water table which dictates the lake level.



Plate 15 : Outlet Lake Goollelal western bank : Storm water is collected from a series of road drains in the surrounding area and deposited directly into the lake system via this outlet.



Scale : 1:25,000

Figure 7a : Northern Section of Catchment showing Outlets, Sumps and Basins
Source: Constructed from Drainage Tax Sheets and Field Observations.



Scale : 1:25,000

Figure 7b : Southern Section of Catchment showing Outlets, Sumps and Basins
Source: Constructed from Drainage Tax Sheets and Field Observations.

Rapid development is currently occurring within the catchment area especially in the Joondalup district with the construction of the new City Centre. With this has come changes in the drainage to the wetland system. The amount of run-off has risen due to large scale paving of the ground, reducing seepage of waters into the soil, evapo-transpiration and interception by plants. Additional inputs also occur due to introduced water discharging through septic disposal systems and excessive irrigation of lawns and gardens. (Jarvis 1991 & Gerritse et al., 1990)

The quality of water drainage into lakes on the Swan Coastal Plain is also considered by many to be poor, containing excess nutrients and other water pollutants. (Arnell, 1982; Congdon, 1985; E.P.A., 1990; Gerritse et al., 1990; Jarvis, 1991 & Walsh, 1991) Whilst pollutants in run-off are of vast importance and thus necessitate mention here, a consideration of their impact is beyond the scope of this study. This study is predominantly interested in the quantity of additional water entering the wetland system through the storm-water drainage network and the affect it is having on the lake water levels. It is stated by (Jarvis, 1991, p.5) that "Stormwater drainage has only a small influence on the total water input of the lake .. [and] is realistically only present between the months of April and October, though some drainage is evident during the summer months." What the relevant information on water quality does do is describe the major sources of additional run-off and infiltration effecting the water balance of the wetland systems.

Jarvis (1991) concludes that the ground-water recharge of residential areas stems from a number of sources. Of the average ground-water recharge, rainfall/evaporation contributes 37%, septic tanks 21%, excess irrigation 15%, recharge from shedding areas (roofs, paved areas) 27%. This will be assimilated with other data and dealt with in Chapter 6.

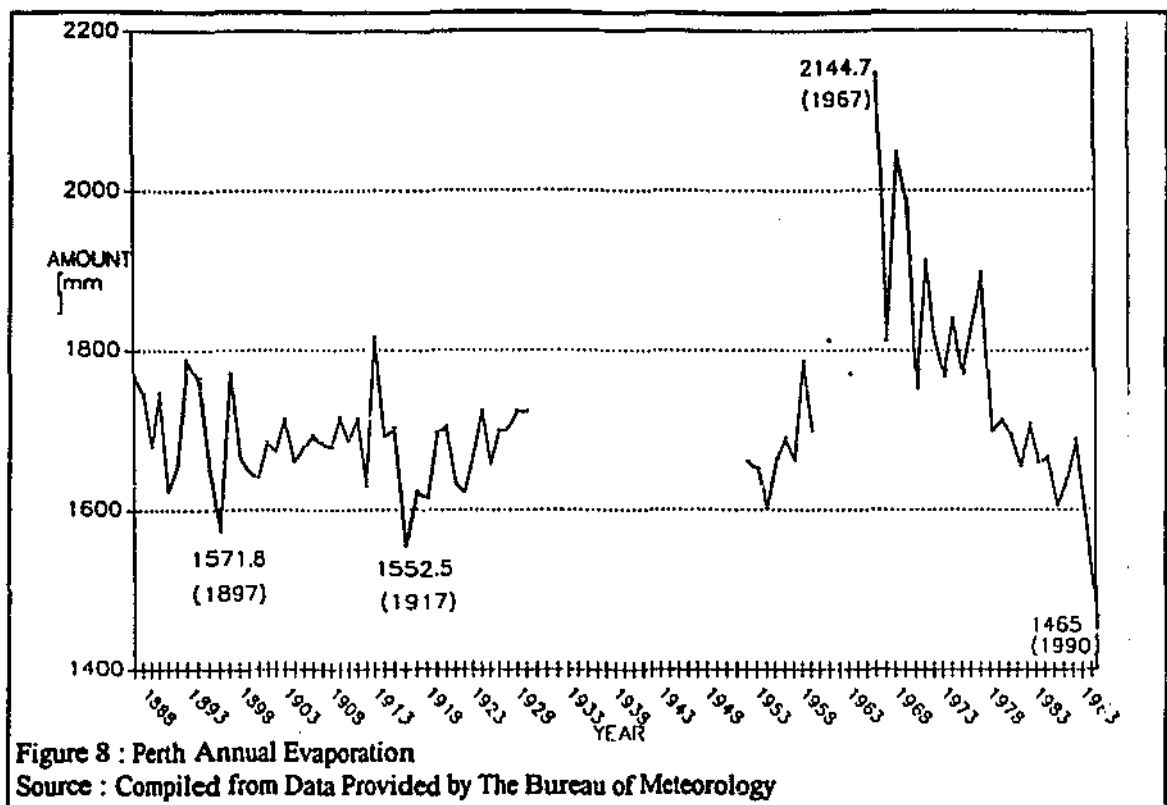
3.2 Climatic Conditions

Climatic conditions impact strongly on ground-water levels and therefore the water levels of the wetland system. Cargeeg et al., (1987), conclude that of the many influences that affect ground-water levels, climatic variation is the most significant. Responding to the recharge of winter rain and the discharge process associated with higher evapo-transpiration during summer, ground-water levels fluctuate each year on a seasonal basis. This fluctuation varies from year to year depending on the amount of rainfall and in what manner it is distributed throughout the year.

The Perth region, in which the Yellagonga Regional Park is located, has a Mediterranean climate which consists of a cool wet winter and a warm dry summer. This is reflected in the mean per annum figures of rainfall, temperature and evaporation for the Perth area. The mean annual rainfall for Perth for the period 1905 to 1991 is 870 mm. The mean evaporation using Class "A" Pan Evaporation for Perth for the period 1967 to 1991 is 1748 mm. For the period 1897 to 1991 the mean minimum temperature for Perth is 13.27 degrees Celsius per annum and the mean maximum temperature is 23.32 degrees Celsius per annum.

About 90% of rainfall occurs during winter, and between the months of May and August rainfall exceeds evaporation. The seasonal rainfall results from westerly frontal systems bringing moist air from the ocean. (Gentilli, 1972)

Evaporation in Perth has a distinct downward trend, see *Figure 8, p.43*, which is currently being researched by the Bureau of Meteorology. So far no reasons for this downward trend have been found. However, if it continues it will have considerable affect on the water levels of the lakes. Decreased evaporation would result in a permanent increase in water levels.



Annual rainfall in Perth and Wanneroo is quite variable from one year to the next. The Wanneroo figures are incomplete and therefore due to the close correlation between the Perth and Wanneroo rainfall figures, (see p.92) Perth figures have been used where Wanneroo figures are unavailable. Both parameters of rainfall and evaporation affect the level of water in the lakes, both seasonally and in the long term.

3.3 Hydrological Conditions

The water table extends beneath all of the coastal plain, this is due to the infiltration of rainfall into the underlying superficial formations. The water contained within this formation is unconfined and the upper zone of saturation forms the water table. See Figure 9, p.44.

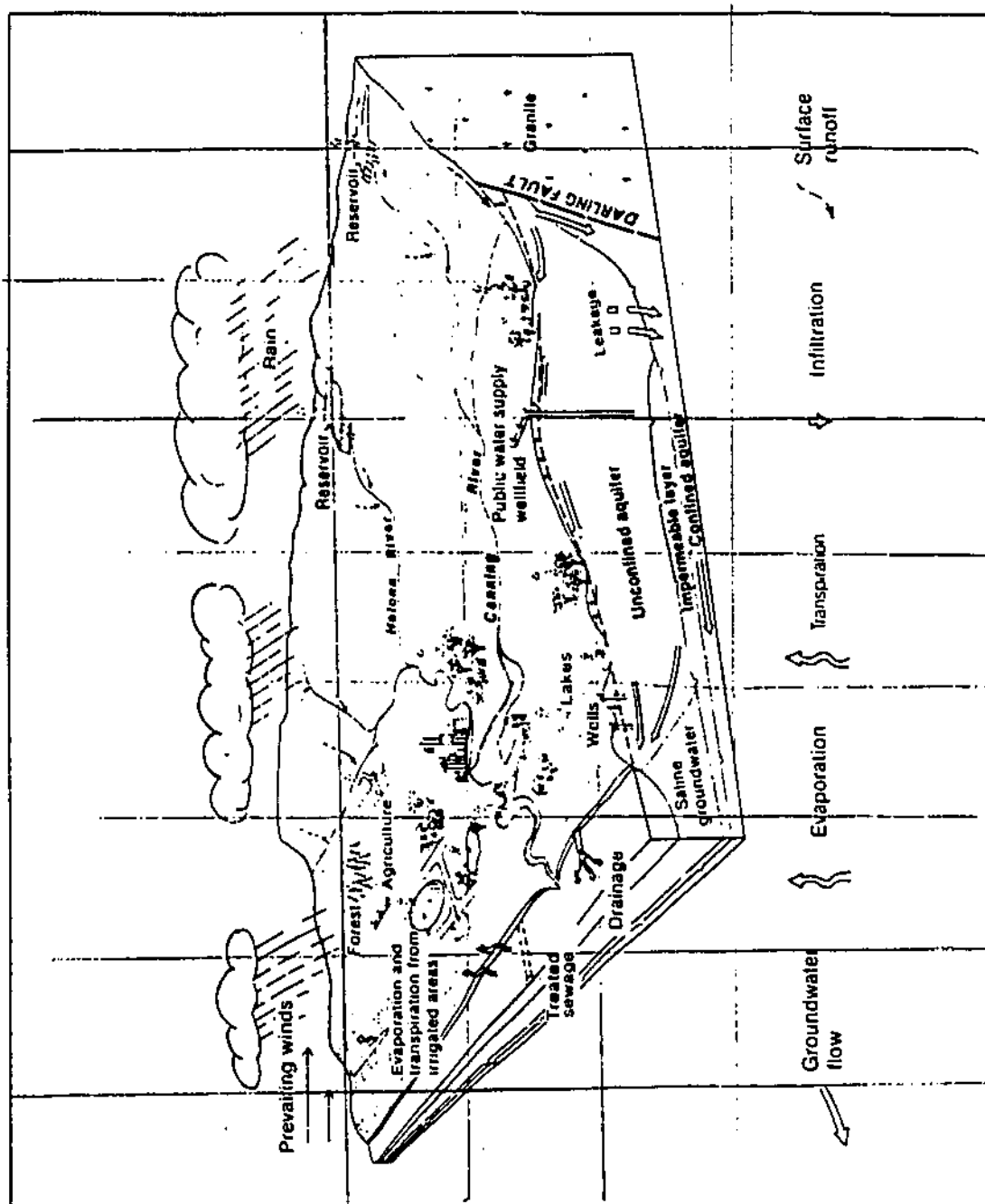


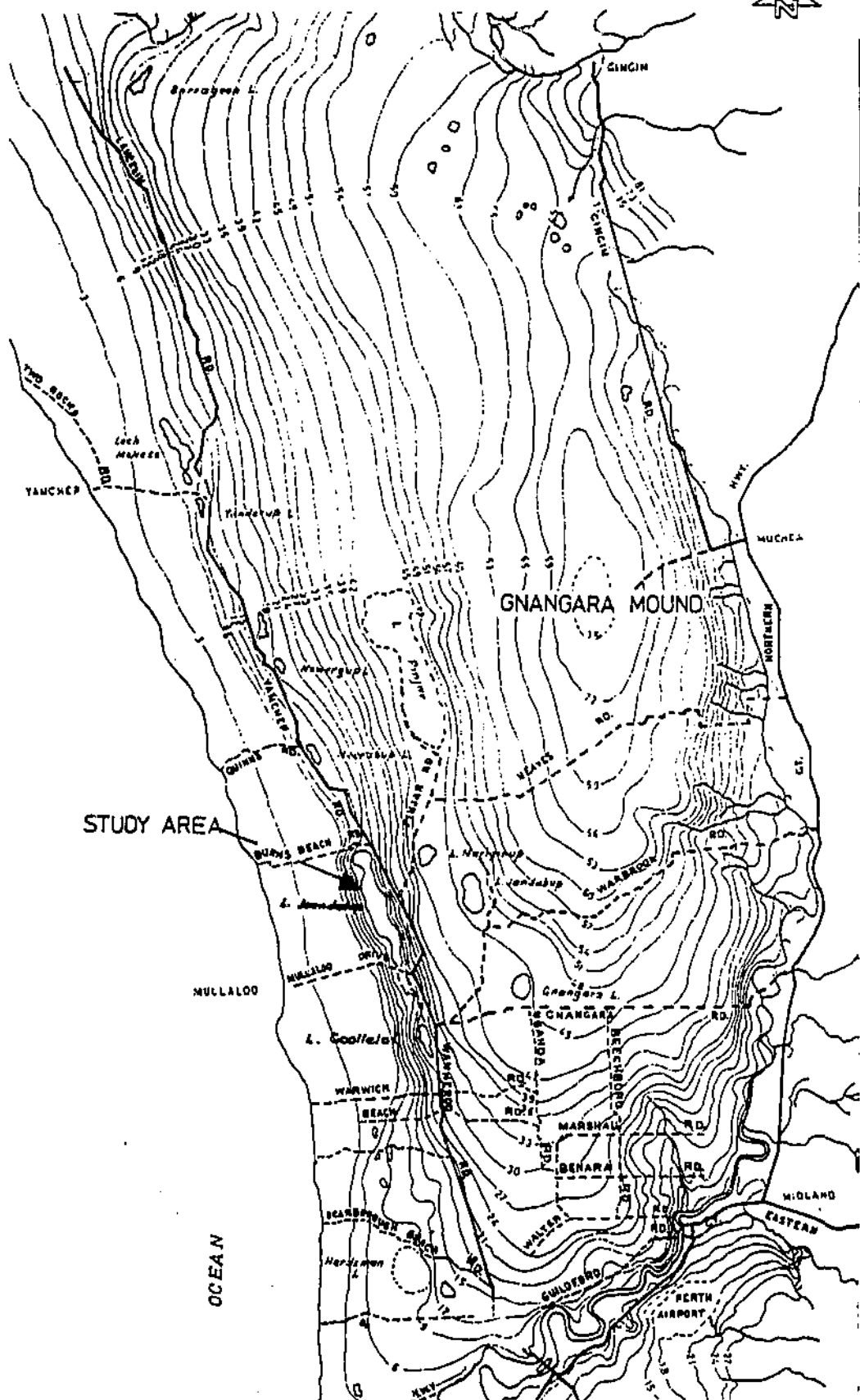
Figure 9 : The Hydrological Cycle
Source : Western Australian Water Resource Council (1989).

The ground-water moves slowly under gravity to be discharged at hydraulic boundaries, such as the ocean. (Allen, 1976, p.23; Dames & Moore, 1986)

The Gnangara Mound is the name given to the water table north of Perth. It forms a pronounced north-south trending ridge, with crests rising to 70m above sea level coinciding with the regions highest areas. The contours show the ground-water flow to be radial, with a steepening of the ground-water gradient in the vicinity of the linear lakes of which Lakes Joondalup and Goollelal are a part. See *Figure 10, p.46*. This is possibly due to the presence of semi-permeable sediments in this area, whereas, the porosity of the coastal strip is reflected in the low gradients of that area. (Allen, 1976, p.24)

The water table undergoes seasonal variations in level and configuration. Water levels are highest in spring after the winter rains and lowest in autumn after the high evaporation period of summer. The wetlands water level follows this strong cyclic pattern. (Allen 1976, p.24; Humpries, et al. 1989, p118)

Lakes Goollelal and Joondalup, like the other lakes of the Swan Coastal Plain are surface expressions of the water-table. Prior to urbanisation their annual water balance would have been dominated by ground-water inflow and evaporation. Urbanisation has altered the annual water balance as urban stormwater systems now discharge directly into the wetland system. Therefore its effective catchment is possibly larger in area than that of its surface water catchment. It is not known exactly how much water is being introduced into the wetland system or how much it is affecting the lake water levels. (Allen, 1976, p.24; Humpries, et al. 1989, p118)



Page 48

Both lakes are shallow, Lake Goollelal's deepest point being 25.47 metres above A.H.D. and Lake Joondalup's deepest point is 15.54 metres above A.H.D. This makes both lakes no more than two (2) to three (3) metres deep in their deepest section. See *Figures 11a, 11b, and 12, p.48-50*. The lakes have a high surface area compared with their volume, making evaporation a critically important process to the altering water level of the lakes. Due to the shallowness of these lakes, a small change in depth represents a large change in volume.

Losses of water to the wetland system occur through direct evaporation, transpiration by plants and ground-water outflow. There do not appear to be any natural outlets from the wetland system, although it has been suggested by Mr E. Crisafulli and Miss M. Cockman that a channel dug to a limestone cave on the western side of Lake Joondalup, about 1933, helps to control high water levels. See *Figure 13, p.51* This claim, after investigation in 1977 by Mr R. V. Ruscoe (Land Information Systems Officer, City of Wanneroo) and Mr P. M. Scott (Water Authority of Western Australian) has been refuted. They believe that whilst water does flow down this channel it does so only until the cave fills, after which the flow slows almost completely. It is to be presumed that the water in the cave slowly drains into the unconfined aquifer. Its affects, however, are insignificant considering the volume of the lake.

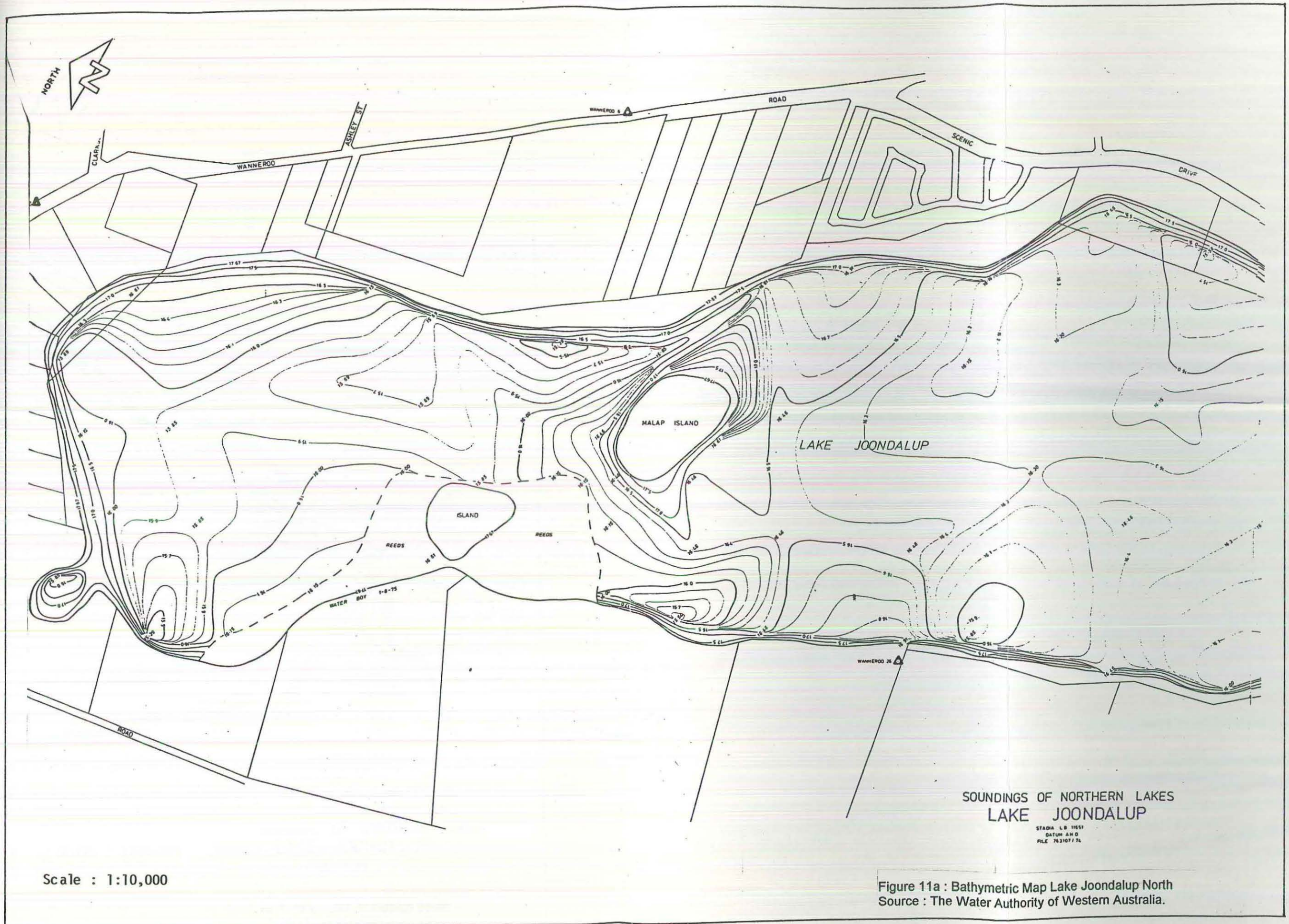
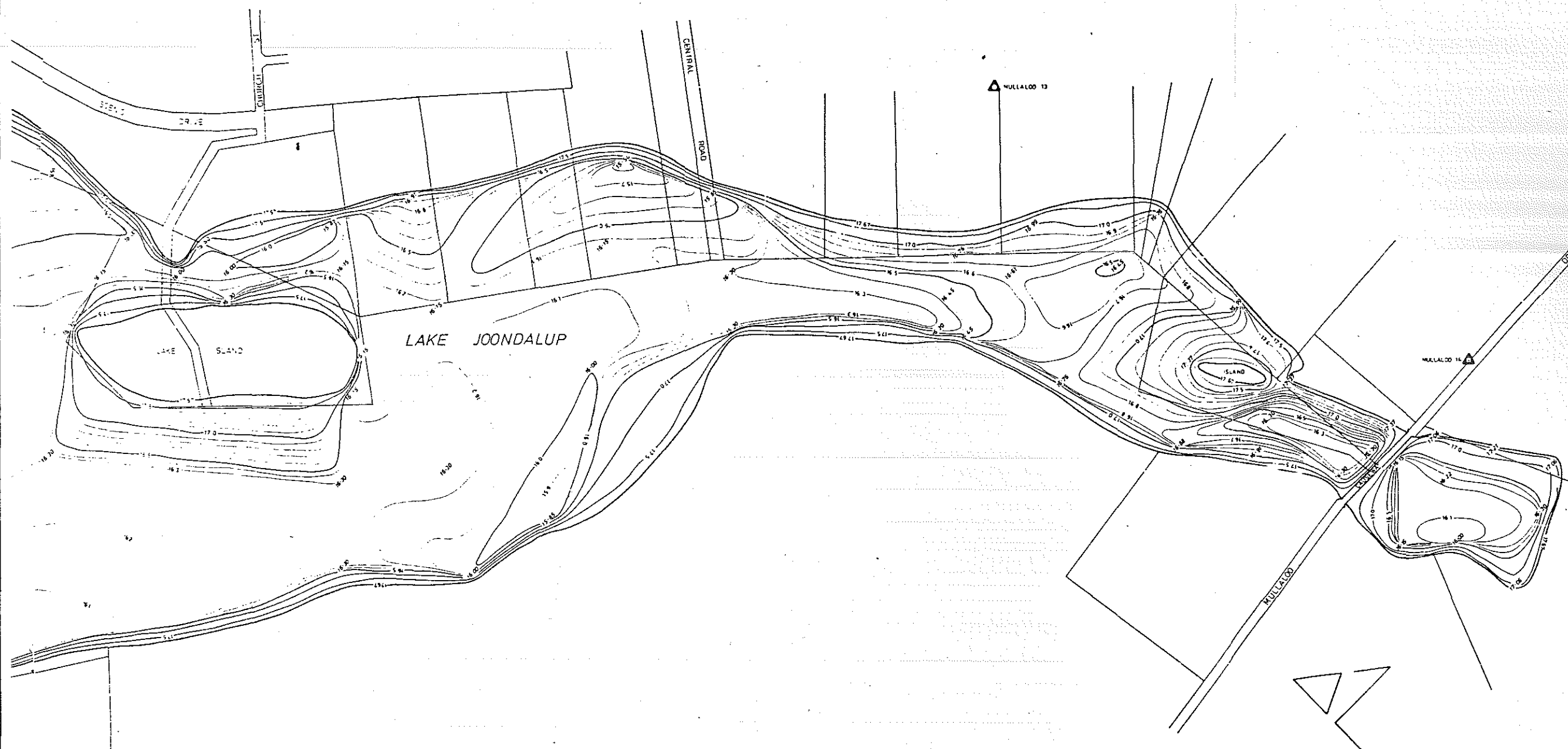
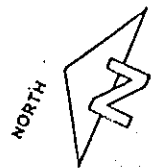


Figure 11a : Bathymetric Map Lake Joondalup North
Source : The Water Authority of Western Australia.



Scale : 1:10,000

SOUNDINGS OF NORTHERN LAKES
LAKE JOONDALUP

FILE 763107/176
STADIA L.S. 11651
DATUM A.H.D.

Figure 11b : Bathymetric Map Lake Joondalup South
Source : The Water Authority of Western Australia.

Scale : 1:33,750

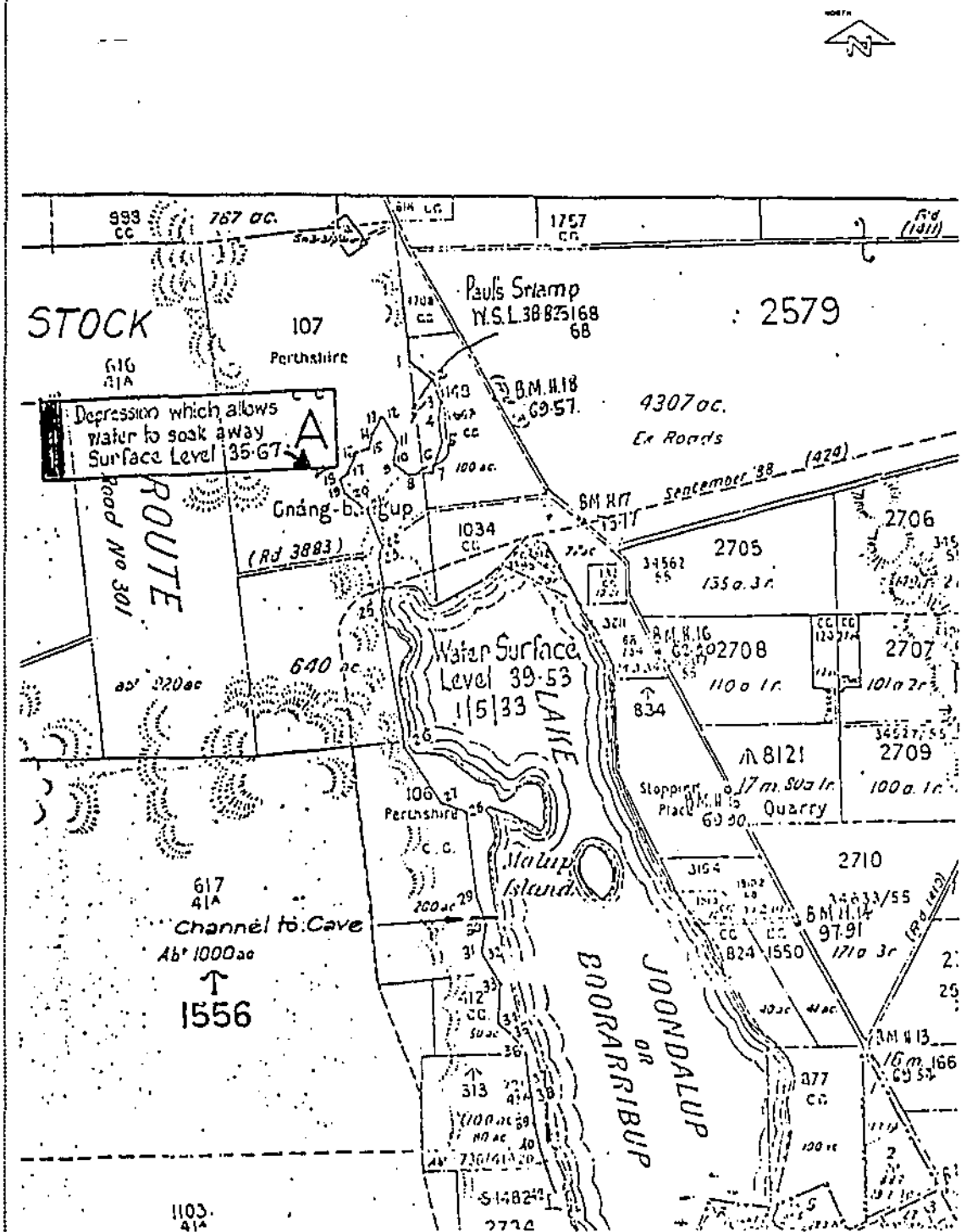
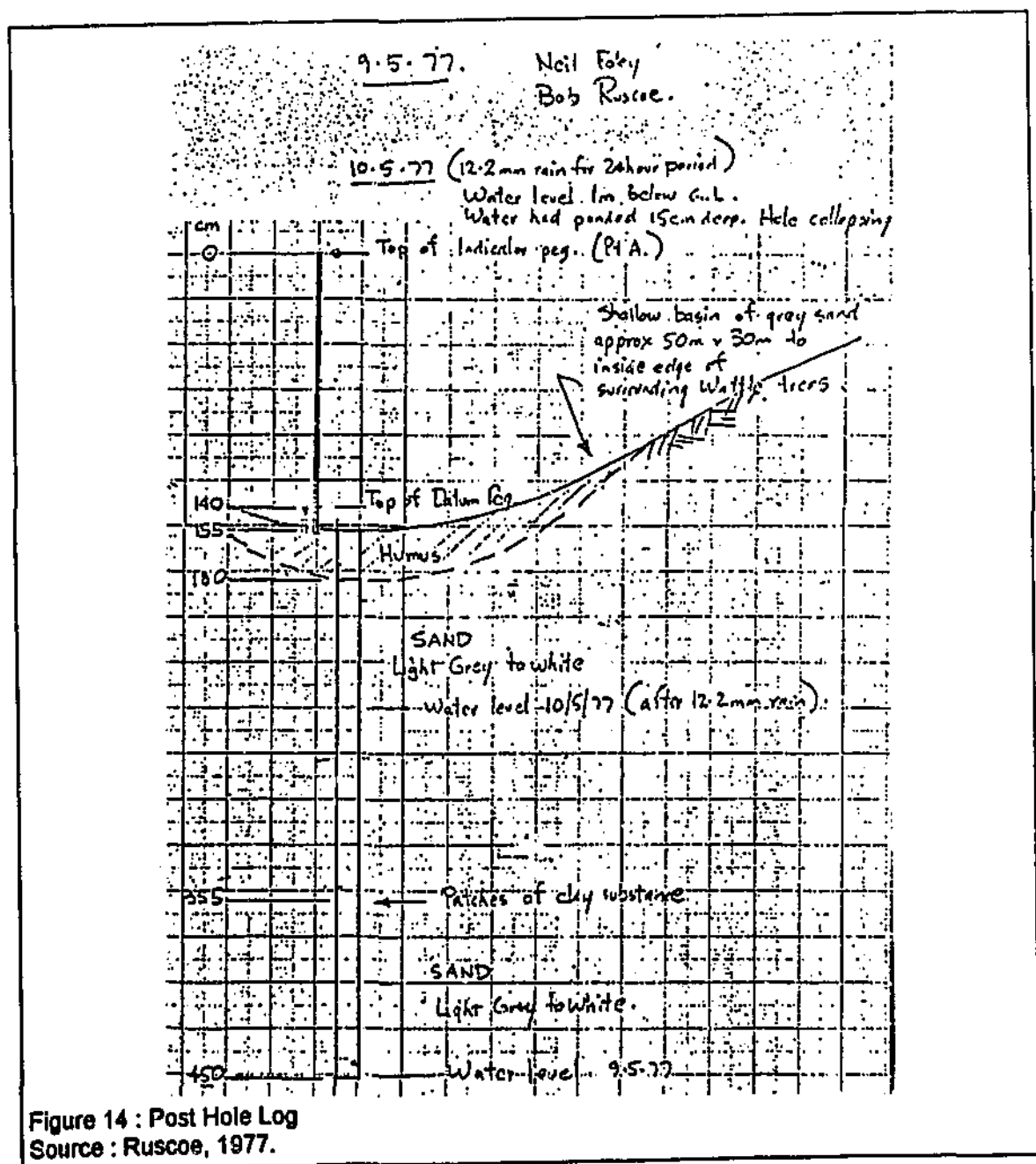


Figure 13 : Historical Map: 1933
Source : Obtained from The City of Wanneroo Archival Store.

Through the sinking of a post hole north of Burns Beach Road it has been established that the western edge of the lake is perched three (3) or four (4) metres above the water table. Whilst the post hole was in place a heavy shower of rain occurred (12 mm), the water ponded to a level of 15 cm above the ground level before subsiding to 1 metre below the ground level. This represented a drop of 1.15 metres in a twenty four (24) hour period. See Figure 14. Therefore it is more likely that at one time the lake filled and overflowed into the damp area north of the lake, indicated on the early map, and drained through the more pervious soil and returned to the water table. See Figure 13. p.51 (Ruscoe, 1977)



This, however, is no longer the case. Substantial road works have taken place in the form of a huge embankment that is to form the new Burns Beach Road, thus effectively altering the contours and therefore the drainage of this area. Therefore, if this damp land has previously been a natural drain for the overflowing lake, this seems to be no longer the case.

Recharge is by rainfall, ground-water inflow and surface water inflow including the drains and sumps discharging into the system. Lake water levels respond very quickly to rainfall.

3.4 Water Quality

Lake Goollelal was sampled and reported on by Congdon during 1979 and 1980. Arnold (1990, p.96), reporting on Congdon's findings states that, "while high nutrient levels were observed in Lake Goollelal, the inorganic nitrogen to phosphorus ratio were low and the levels of chlorophyll *a* observed suggest that Goollelal is less eutrophic than Joondalup".

Davis, Rolls & Wrigley (1991) in a survey of the environmental quality of sixteen wetlands on the Gnangara mound, classified Lake Goollelal as fresh, with low concentrations of total N and chlorophyll *a*. Lake Goollelal however has the highest alkalinity of all wetlands tested. During the course of the survey *Microcystis* and *Anabaena* were recorded at Lake Goollelal and Lake Joondalup. Organochlorine residues were also detected in sediment at Lake Goollelal. Davis, Rolls & Wrigley (1991) however, concluded that Lake Goollelal was suffering only low levels of enrichment.

Lake Joondalup's water quality has been extensively studied. (Congdon, 1973; 1975; 1979; 1985; 1986; Congdon & McComb, 1976; Davis & Rolls 1987; Davis, Rolls & Wrigley, 1991) This data shows that the seasonal changes in the volume of Lake Joondalup greatly affect the concentration of dissolved substances.

Congdon (1975, p.21) reports that "the relatively high levels of phosphorus and nitrogen in the water and the occurrence of algal blooms, justify the provisional designation of the lake as *mildly eutrophic*".

Davis and Rolls (1987) use species richness as one indication of the environmental quality of wetlands. Their research showed Lake Joondalup to be poor in comparison to the other lakes tested. More specifically they reported elevated levels of nutrients to be present in Lake Joondalup which was consistent with all lakes tested, except Lake Jandabup. It was concluded that this would cause water problems associated with eutrophication. During the monitoring of Lake Joondalup the presence of metaphyton was detected which reduced light penetration. Lake Joondalup, along with Thomsons and Jandabup Lakes had elevated salinity in the summer of 1986. These results confirm Congdon's (1975) earlier findings that Lake Joondalup is a mildly eutrophic lake.

Davis, Rolls & Wrigley (1991) in this later study found Lake Joondalup to be mildly saline and high in alkalinity. Lake Joondalup fell in the mid range of the sixteen wetlands tested for total P, total N and chlorophyll a. Lake Joondalup together with Lake Goollelal and Gingin Brook were the poorest wetlands in terms of species numbers and richness. It was concluded that Lake Joondalup was showing signs of only low level enrichment.

The Water Authority of Western Australia provided data that suggests that these levels have not altered over time for Lakes Goollelal or Joondalup.

Sampling at different times of the year, however, may give widely varied results as the winter rains significantly dilute salts and nutrients, and summer evapo-concentrative processes cause readings at that time of the year to be substantially higher.

3.5 Topography, Geology and Soils

The topography of the Swan Coastal Plain although undulating has only a small gradual increase in elevation from west to east until quite near the Scarp. The wetland system lies within the Spearwood Dune System which is characterised by its low, hilly to undulating terrain, with a core of sandy limestone, capped by secondary calcite, overlain by siliceous sand. (McArthur & Bartle, 1976)

There is no external drainage in the Spearwood Dunes. It is what is known as a Karst Region, in which all of the drainage is by underground channels. The water sinks through the surface sand into the porous aeolianite limestone below. Subterranean drainage is by percolation through the aeolianite, this has led to the formation of underground caves. It is believed that the line of caves extending north-south down the coast represents the collapse of an underground drainage system of linked caverns. (McArthur & Bartle, 1976; Moore, 1978; Seddon, 1972)

The C.S.I.R.O. Division of Land Resources Management (1976) has surveyed and classified the soils of the Yellagonga Regional Park area. There are two main soil types in the Spearwood Dunes, the Karrakatta sands and the Spearwood Sands, (also known as Cottesloe Sands) and it is these two that dominate within the study region. Karrakatta sands have a grey brown sandy surface passing into bright yellow sand and often with limestone within two metres. These sands extend from the top of Lake Joondalup, north-east around the lake and most of the way along the eastern shore. The Spearwood sand, gently sloping to steep irregular banks of depressions, it is characterised by its brown sandy surface over bright yellow-brown sand with limestone often within one metre of the surface. This Spearwood sand extends almost entirely around Lake Goollelal and the western side of Lake Joondalup. Limestone ridges and outcrops form the high points on the coastal plain; they occur

throughout the Spearwood sand and are visible, due to exposure by wind action, along the western side of Lake Joondalup. See *Plates 16 and 17, p57.*



Plate 16 : Limestone outcrop Western shore of Lake Joondalup

The other soil present within the Yellagonga Regional Park is the Beonaddy sand, which has a flat topography and is found around the bottom eastern side of Lake Joondalup and the top of Beenyup and Wallubuenup Swamps. It is characterised by a very dark grey sandy surface over very light grey sand, sometimes with brown mottling, with the water table often within one metre.

(McArthur & Bartle, 1976)

The lake floors themselves have not been classified by the C.S.I.R.O. Allen, (1976, p.22; 1981, p.38), however, states that all the lakes of this region contain lacustrine sediments of biogenic origin, up to 10 m in thickness, consisting of calcareous clay, peat, diatomite, bog & freshwater limestone, and peaty sand. This is basically an organic peaty sediment made up of decayed plant material, shells and sand. This layer becomes sandier closer to the edge

where the fringing vegetation is present. In bare areas, however, where the gradient is low, the peaty material continues up onto the bank forming mud flats. These areas are frequently exposed in the summer months, and become soft and deep in the winter months.



Plate 17 : Limestone outcrop Western shore of Lake Joondalup

The eastern shores of Lake Joondalup and Lake Goollelal have a low gradient, rising slowly over several kilometres to form a ridge peaking at 70 A.H.D. See *Plates 18 and 19, p.58*. This results in the catchment area to the east of the lakes being quite large taking in all of the Wanneroo town site and much of the adjoining Wangara industrial area. The northern end of Lake Joondalup also has this low gradient. The wetland catchment extends up to 5.5 km. northward, covering several small swamps and inundated areas and much natural bushland. (See *Figure 6, p.32*)



Plate 18 : Eastern shore of Lake Joondalup gently rising : The low gradient results in the catchment area stretching for several kilometers to the east. It peaks at 70 A.H.D.

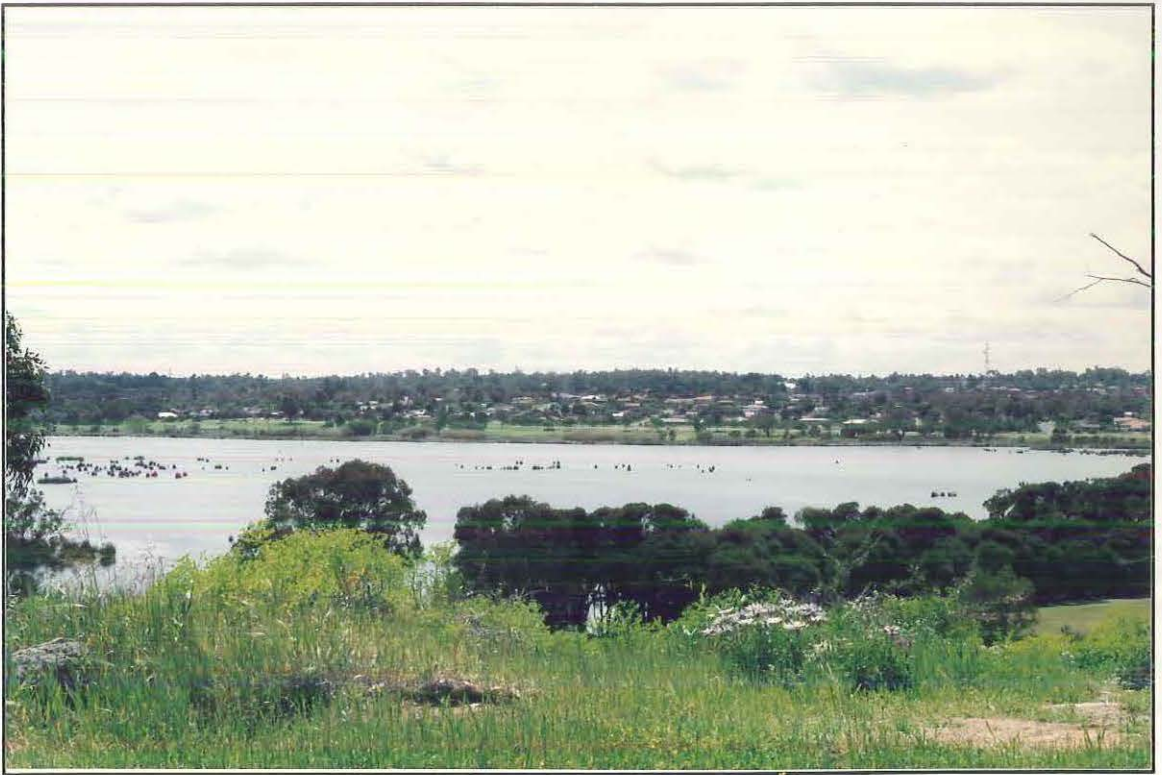


Plate 19 : Eastern shore Lake Joondalup (background) showing the low gradient : The foreground depicts the much steeper gradient on the western shore. Note the tree-tops above which the photo was taken.

The western side rises quite sharply by comparison peaking at 65 metres A.H.D. within 1 km. See *Plates 20 and 21, p.60*. However, there is a low lying area between the two lakes that is quite extensive. Beenyup swamp and Wallubuenup swamp occur in this area. They are seasonally wet areas that contain some open water in winter and they support dense vegetation. (DOLA, 1986a; 1986b)



Plate 20 : Western shore Lake Joondalup (background). The foreground shows the disturbed area of the eastern shore, it was once an inert (eg building rubble, sand and soil) land fill site in the 1970s. Note the *Typha orientalis* that has taken over the area.

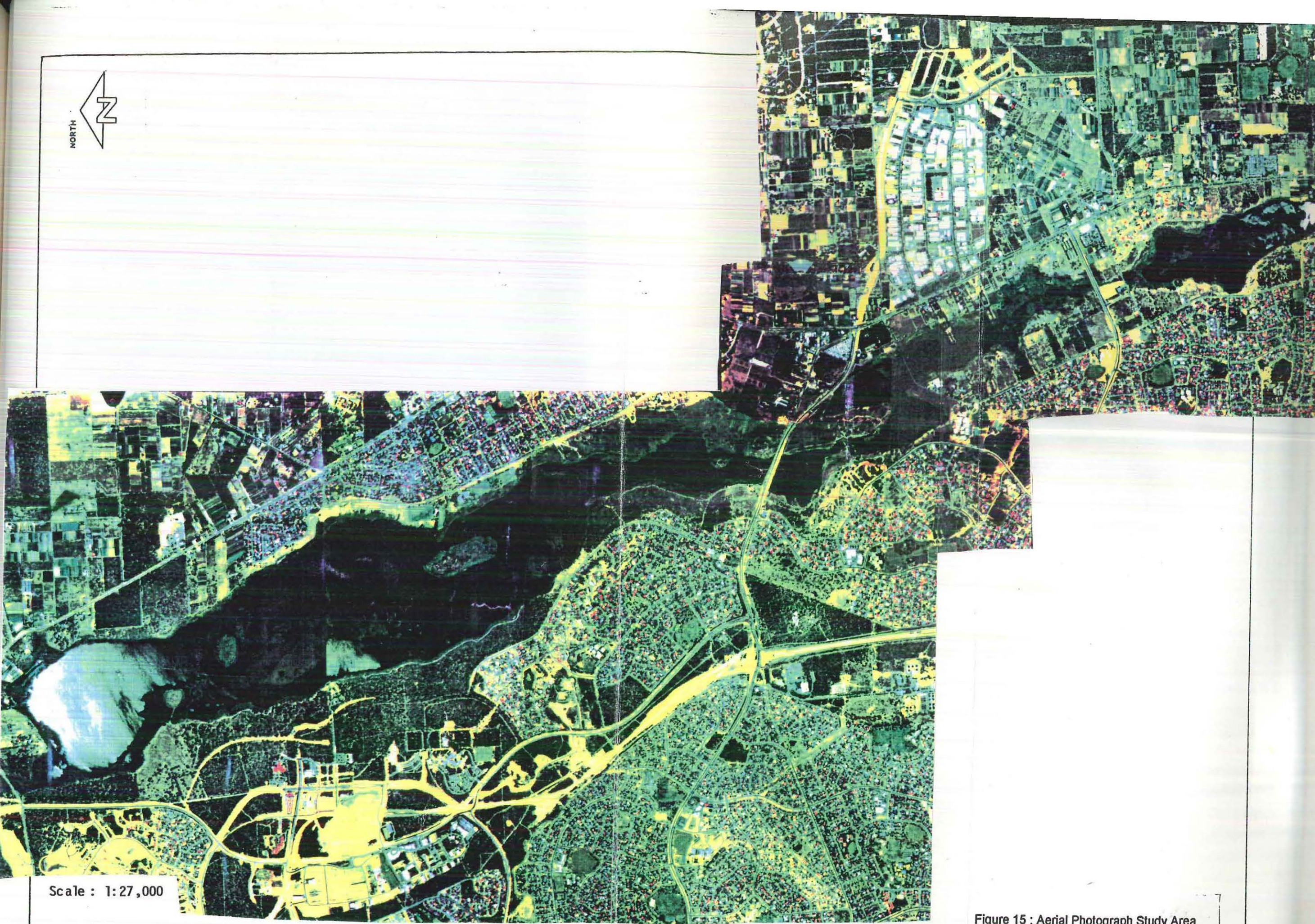
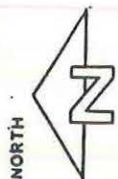


Plate 21 : Western shore rising sharply (background) : Note the flat gradient of the eastern bank in the foreground and the invasion of exotic species (eg pampas grass)

3.6 Vegetation

The Yellagonga Regional Park offers a diverse array of fauna and therefore habitats. Many surveys, (Congdon and McComb, 1976; Froend, 1990 & Seddon, 1972) have been undertaken on this area with particular emphasis on Lake Joondalup. This study utilises existing information and combines it with current field observations.

The most distinct feature of the vegetation of the Yellagonga Regional Park is the distinct zones within which the different communities lie. These distinct zones are clear in aerial photographs of the area, *See Figure 15, p.61*. The different storeys are easily discernible from the water, *See Plate 22, p.62*, and through direct observation on land.



Scale : 1:27,000

Figure 15 : Aerial Photograph Study Area



Plate 22 : Vegetation zones Yellagonga Regional Park : Note the transitional zone containing Acacias, Banksia, Tuart, Jarrah and Marri.

Lining the edge of the lakes is the emergent aquatic fringing vegetation, dominated by sedges and rushes. The main species found at Lake Joondalup is the sedge, *Baumea articulata*, which is found in pure stands on the western, northern and north-western edge of Lake Joondalup, growing up to 3 metres in height. In disturbed areas, the bulrush, *Typha orientalis*, is found usually in association with either the *Schoenoplectus validus*, in the more disturbed areas such as the south-eastern edge of Lake Joondalup, or *Baumea articulata* in areas less disturbed such as the eastern edge of Lake Goollelal.

The next zone is the fringing paperbark woodland, which consists of a narrow belt around the margins of the lakes on seasonally inundated soils and stands up to 7 metres in height. The dominant species in these woodlands is the paperbark, *Melaleuca raphiophylla*, with smaller quantities of the flooded gum, *Eucalyptus rudis* present on Lake Island. Stands of dead paperbarks are also found, a testament to long term rising lake levels.

A small transitional zone occurs on the deeper soils of the slope leading down to the lake and consists of *Melaleucas*, (Paperbarks), *Acacias*, *Banksias*, as well as the Tuart-Jarraah-Marri open forest of the next zone. This transitional zone reaches 15-18 metres.

Finally on the shallower drier sites on the ridges and slopes the Tuart-Jarraah-Marri open forest takes over. This upper storey reaches a height of 25 metres. Much of the understorey in these forests is sparse or absent, due probably to the past grazing of stock.

CHAPTER 4 : RECONSTRUCTION OF LAKE LEVELS

4.1 Historical Records

The nomenclature section of the Department of Land Administration provided information as to the first people to explore the area. Additional information on the origins and variety of names for Lake Goollelal and Lake Joondalup was also obtained. Records of early explorations through the study area, as well as surveyor's field books and the maps that were produced from these field books were then examined, and any relevant information about the lakes and their water levels extracted. The following is a chronological account of the varying lake levels compiled from these sources.

Where appropriate the spelling and language of the diaries has been used without correction to give a more realistic portrayal of the lakes. As the diaries purpose is to create maps punctuation is non existent therefore direct quotes do not contain any punctuation. However, in some cases it was necessary to help the reader understand the meaning of the quotes.

The earliest written record associated with the now Yellagonga Regional Park is the exploration diaries of John Butler. Butler first discovered the lakes on the 20 March, 1834 whilst searching for lost cattle. Butler (1834, p.280) simply commented that there was a "large lake" and suggested the land was worth surveying.

The lakes were next commented on by Grey (1838, p.292) who encountered them on an exploration northward, "about 5 pm. we reached a lake distant about 15 miles from Perth, and called by the natives Moolooore: we halted here for the night. ... four more natives joined the party; ... They said that although the lake was called Moolooore, the name of the land we were sitting on was Doon-da-lup."

The first official survey of the lakes was in 1838 by Thomas Watson. Original Plans Swan 36 and Swan 39 entitled "Survey of the Lakes, Joond-alup and Boor-arribup", were produced. Swan 39 is dated 16 March 1838 and is of the northern section of Lake Boor-arribup (Joondalup) and shows the lake as having open water and a fringing of reeds. Swan 36, also dated 16th March 1838, is of the southern section of Lake Joond-alup (Joondalup). The plan shows open water around Lake Island, but where the lake narrows it is shaded and annotated "high bulrushes" (probably *Typha orientalis*). The eastern area is "thick with tea trees (paperbarks) and rushes" (where the term rushes is used, rather than bulrushes, it is likely that the species being referred is *Baumea articulata*), this shading occupying all of the southern section of the lake except two (2) small patches close to each bank and a larger area in the south-western corner which is annotated "deep open water". Beenyup swamp is also shown and is noted as being "thick with tea trees and rushes". Wallubuenup Swamp is depicted with tea trees and rushes on its north-eastern bank. The rest of its area is annotated "rich soil spring land". See Figures 16 and 17, p.66-67.

There are no field books in existence, that deal with the construction of these plans, therefore, analysis is of the plans alone. The plans depict Lake Joondalup with less fringing rushes, but with more rushes and paperbarks on the southern section than we see today. The area to the southern end of Lake Joondalup was narrow with decreased surface area, suggesting a lower water level at that time. Nonetheless, colouration suggests that there was some water covering this area, as areas which had no water were left white. A current bathymetric map has been used to ascertain that the areas of open water depicted on the plans coincide with the deeper areas of the lake today.

In order to give as accurate a measure as possible a planimeter was used to measure the area of Lake Joondalup on plans Swan 36 & 39. The process was then repeated using a current 1:25,000 map with a known water level.

This process gave the approximate change in surface area of the lake. A scale rule was used to check the accuracy of this method. All chain figures were converted to metres using the formula:

1 chain = 66 feet = 20.12 metres.

Using this method, a decrease in the width of the lake at several points coincided with a decrease in overall area that was found using the planimeter. This established where the historical lake edge periphery was, and with the use of a bathymetric map, an approximate depth of 17.00 A.H.D. for Lake Joondalup was established.

Original Plans, Swan 41A and 41B depict the north-western tip and south-eastern portion of Lake Goollelal respectively. They are undated and no surveyor's name is apparent. It can, however, be deduced that Watson also drew these in plans in 1838 as Swan 36 has annotated on its bottom margin "Joins Swan 41a". The lake is shaded around its margin and annotated "this portion thick with tea trees". The centre, however, appears as open water. By applying the above process, of measuring area and width, to the historical plans of Lake Goollelal, and a 1:25000 map of Lake Goollelal, the difference in size can be established. The use of a bathymetric map of Lake Goollelal established an approximate level of 26.5 A.H.D.

Following Watson, John Septimus Roe went through the area in May 1839. Field Book 1 depicts Boorribup and Joondalup as open water with only the very southern section, which is now located south of Ocean Reef Road and joins Beenyup Swamp, as being "water and rushes". It can be assumed,

therefore, that the water level had increased since Watson's surveys in 1838. No scale was given in Roe's field book and no map is available. The calculation of the water level relied solely on examination of Roe's sketch against the bathymetric map. The water level approximation is 17.5 A.H.D.

Roe also sketched Lake Kola-lup, (Goollelal), in Field Book 1, as being dry with only a band of water around the edge. It is unclear as to whether this information was from the May 1839 or the November 1841 trip. Both surveys covered almost identical routes at this point and one set of notes and sketches was overlaid on the other in the diaries. As the water levels of the lakes fluctuate concurrently, it is likely to be November 1841 as Joondalup was showing no signs of dryness in 1839. A calculation for November 1841 using a bathymetric map of Lake Goollelal assumes this was the case. The current bathymetric map has two (2) sections of reeds mid-water showing a level of 25.93 A.H.D., a level that would leave pockets of water around the reeds as is seen in the historical plans. It can, therefore, be construed that at the time of Roe's observations the water level of Lake Goollelal was near this figure. Therefore, a level of 26 A.H.D. approximates the level at that time.

Original Plan, Swan 37, titled "Rough Sketch of Lake Joondalup" by T. Watson with additions by A. C. Gregory, is undated on the map itself, however Battye Library date the sketch as being between 1840 -1846. This sketch presents Lake Joondalup as an expanse of water which is shaded light and dark blue; a fine line divides the areas. This author suggests that this shading represents shallow and deep water, and as no exposed bed is shown and parts of Beenyup and Wallubuenup Swamps are depicted as having open water, the water level was high. Using the Bathymetric map for comparison, a water level of approximately 18.0 A.H.D. is suggested for this period.

In January and February of 1842, A. C. Gregory surveyed the area from Lake Gullillillup (Goollelal) through to Lake Joondalup. Original Plan, Swan 41, "Swan Location - Lakes North of Perth Location 103 January 1842", was the result of the Gullillillup, (Goollelal) area survey. Lake Gullillillup, (Goollelal) is depicted as being covered in high reeds and peaty soil except for a band along the south-western side which is open water. See *Figure 18, p.71* Using the previously described technique, (p.68) a water level of 25.5 A.H.D. has been calculated.

Original Plan, Swan 35a, "Swan Location - Gnangara, Survey of Lakes North of Perth Loc'n 104, Feb 1842", and Original Plan, Swan 55, "Survey of Locations 106 and 107, Lakes North of Perth, by A. C. Gregory, Feb 1842", were the results of the Joondalup area survey. These plans depict Lake Joondalup as an expanse of water containing two islands situated in open water. The southern section, however is depicted as water and reeds with a section of open water in the most south-western tip. The reconstruction technique revealed a water level of 17.0 A.H.D.

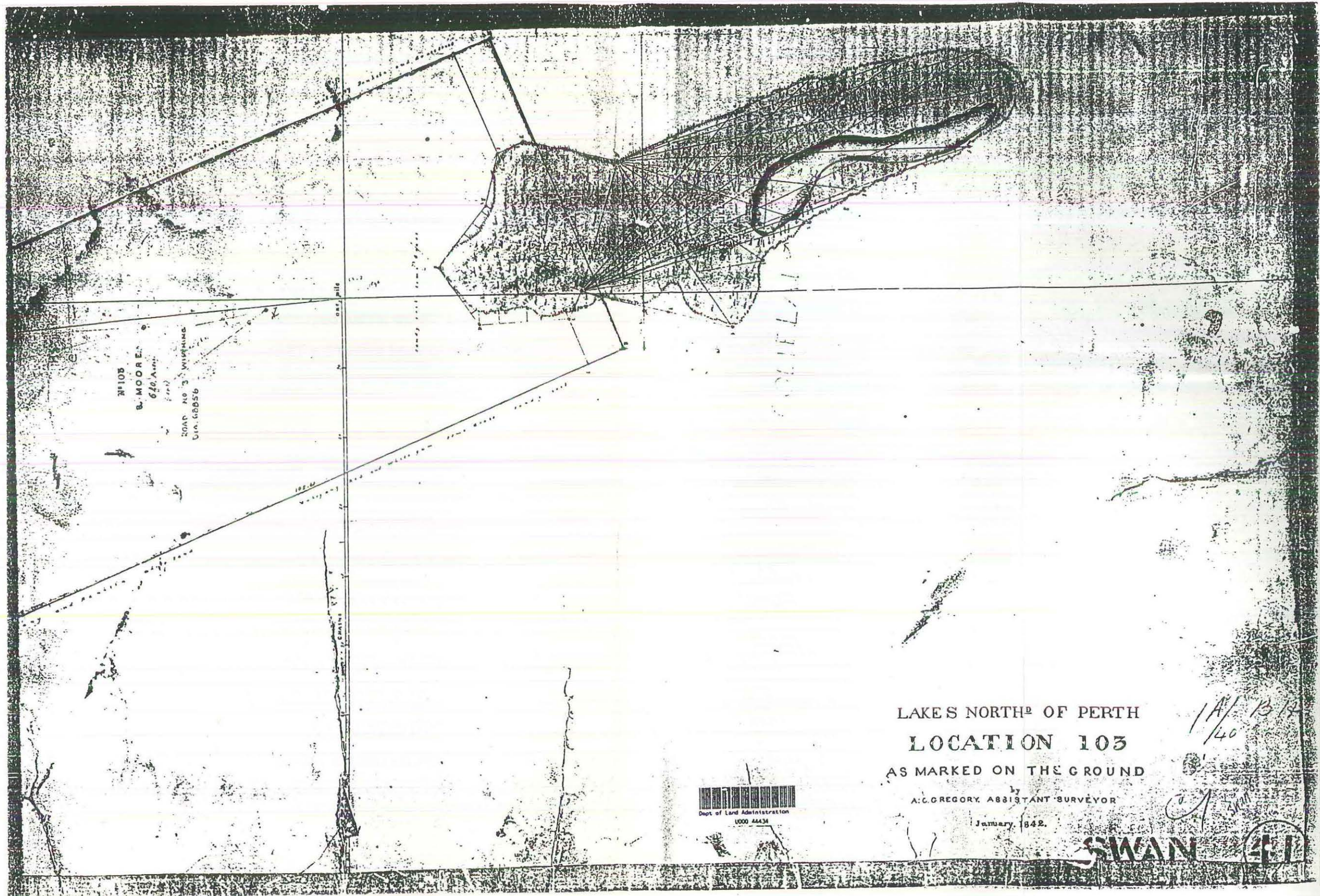


Figure 18 : Original Plan, Swan 41

A. C. Gregory's Field Book Number 2, January 1842, reinforces this interpretation of the maps. It suggests that Lake Goollelal was partially dry. Gregory outlines the area transversed in order to produce the map. The periphery of Lake Goollelal was described in a trigonometric survey by Gregory, (1842, p.3-13) "soft mud, lake, reeds no water ... short reeds no water ... low swampy land ... reeds no water ... reeds no water ... soft mud reeds ... soft mud ... mud water mud water soft mud water mud ... reeds". This account implies that the periphery of Lake Goollelal was covered with mud and reeds, with only intermittent patches of open water, as depicted on the Original Plan, Swan 41. Gregory (1842) also recorded that Wallubuenup Swamp and Beenyup Swamp were covered in reeds with mud but no water. Lake Joondalup was referred to by Gregory (1842, p.31) as a body of open water. This would imply that the approximated water levels for the lakes are correct.

Chauncey, (1842a, p.4) in Field Book Number 14, writes of Lake Goollelal in January 1842, "width of Lake Goollelal 2455" This figure coincides with the measure used on Gregory's Original Plan Swan 41. This confirms the accuracy of the plan. Chauncey in November 1842 commented at length on Lake Goollelal and its surrounding area, "High reeds on fine black dust for about 500 further to the water, a little way in this fine black or brown soil when it is wet a stick 10 feet (3.048 m) long went down with the greatest ease" (1842, p. 77-79) Several sketches that go with this section show a distance between the edge of bushes and the water of Lake Goollelal. See *Figure 19, p.73*. This implies that the water level was low, as there was a distance of 7.62 m (25 feet) to the water's edge from the reeds which are normally fringing vegetation. The water level would have had to have been as low as 25.8 A.H.D.

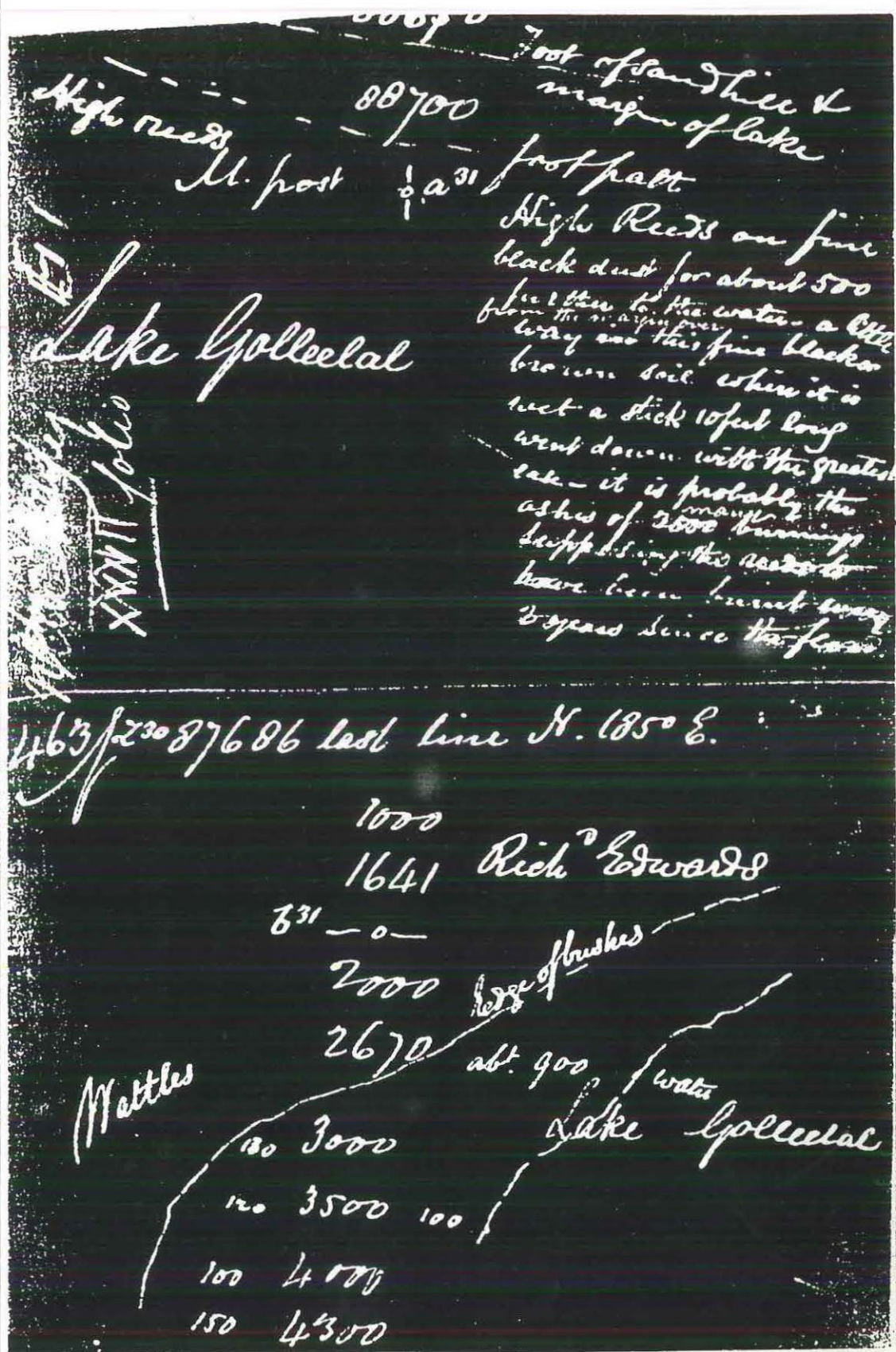


Figure 19 : Chauncey, 1842a, Field Book 14

Chauncey again visited Lake Goollelal on the 30 January 1844. In Field Book Number 13, Chauncey (1844, p.4) refers to "water edge of lake". This author interprets the phrase to mean that the water had risen to the edge of the lake, giving an approximate level of 26.5 A.H.D.

Chauncey visited Lake Borarabup (Joondalup) in February 1844. In Field Book Number 13, Chauncey (1844, p.17) refers to the Bulrushes surrounding Lake Joondalup "Bulrush bed peaty soil dry in summer". This implies that the fringing vegetation of Lake Joondalup is not submerged in water but that the level has sufficiently dropped to leave dry peaty sand. Therefore, an approximate level for Lake Joondalup would have been 16.5 A.H.D.

There is a break in the available data for the lakes until 1862, when R. Quinn surveyed Swan Locations 412 & 820. Quinn, (1862, p.1-5) in Field Book Number 4, maps Lake Joondalup as the eastern boundary of the property 412. He depicts the lake as being full with no fringing reeds. It is therefore interpreted that the lake was full. An approximate level of 17.5 has been calculated.

The next available information on the lakes is from 1867, when J. Cowle surveyed Lake Goollelal. He drew up subdivision 709. In Field Book Number 2, Cowle (1867, p.27) has noted "full" and "water and reeds". The sketches indicate that the water came up to the fringing vegetation. An approximate water level calculated for this is 27.00 A.H.D. Original Plan, Swan 35, was compiled from the information collected by Cowle (1867). The map also gives the impression that Lake Goollelal was full at the time of the survey which further reinforces the interpretation of the surveyor's diary.

In Field Book Number 6, Cowle (1872, p.32) made notes on subdivision 587. The sketch that accompanied the notes also indicated that Lake Goollelal was full. Therefore a level of 27.00 A.H.D. is recorded for this date.

Another break in the sequence of available data appears at this point. The next accessible information is for 1884. In this year W. A. Saw comprehensively re-surveyed the area surrounding both lakes in the process of subdividing additional land for settlement. Field Book Number 4 (p.42-56), and Original Plan Swan 136 "Swan Location - Vicinity of Lakes Jandabup, Joondalup, Gnangara & Coollelal, by W. A. Saw, 1884", is a direct result of this work. Additions were later made to the plan in 1899. In both the surveyor's diary (Saw, 1884a) and the plan (Saw, 1884b) only parts of both Lakes Joondalup and Goollelal are sketched. They do, however, indicate open water for both lakes. It is, therefore, approximated that the water level at this time for Lake Goollelal was 27.00 A.H.D. and for Lake Joondalup it was 17.5 A.H.D.

Original Plan, Swan 137, "Swan Locations - Vicinity of Lakes Jandabup, Maringinup and Joondalup, Locations 132, (Resurvey), 824, 1034-5.1900.7/525. Y526, undated & unsigned", incorporates much of the data recorded by Saw in Field Book Number 4. As it is a re-survey of the above plan it is presumed that it occurred after 1884, probably later in the same year or early in the following year. Both the plan and the book depict Lake Joondalup as overflowing its banks in the northern section, suggesting a high water level. The other lakes in the plan are also depicted with open water and wide swampy banks, suggesting a high water table throughout the area. Therefore, an approximate water level has been calculated with the use of both maps and the surveyor's diary. A depth record of 18.00 A.H.D. for Lake Joondalup and 27.00 A.H.D. for Lake Goollelal is recorded.

At this point the way in which maps of this area were drawn was changed. No longer did the surveyor make comprehensive notes with sketches in the field for the preparation of maps at a later date. Maps were drawn without the aid of sketches, and comments regarding the vegetation, soil and water of the surrounding area were no longer noted. This means that although maps were

produced after this date no notes were made. The following is a direct interpretation of these maps.

Public Plans C1 and C4 (Office of Surveyor General, 1890) depict the southern end of Lake Joondalup with a dotted line; Lakes Maringinup, Jandabup, Big and Little Carine, Balcatta, Gwelup and others are depicted in the same way. This is interpreted as representing a dry lake bed, as the outline has been drawn in with a dotted line. It is inferred that the surveyor could see where the water should be, and had been, but that there was no water there at the time. In order for the southern section of Lake Joondalup to dry out the water level must have dropped to a level of approximately 16.6 A.H.D.

Lake Goollelal on the same set of maps is drawn in with a full line. It is inferred, therefore, that although many other lakes in the area were dry and were drawn with dotted lines, Lake Goollelal still had water in it. A level of approximately 26.5 A.H.D. has been calculated.

The last of the Original Plan series covering the study area was produced in 1903. It is a compilation map of various surveys dated 1841 to 1907 and is titled Swan 270: "Swan Locations No. 1315 (Plan west O.P. 271) in the vicinity of the Marmion Townsite and Wanneroo Road, compiled by N. S. Bartlett". Bartlett, (1903) depicts Lake Goollelal subdivided throughout its entire basin, but still with a solid shore line. The plan is annotated "Deep light boggy soil covered with bulrushes". This implies a very low water level. The size of the lake, when measured with a planimeter and scale rule, has not decreased. The reconstructed water level was approximately 25.5 A.H.D.

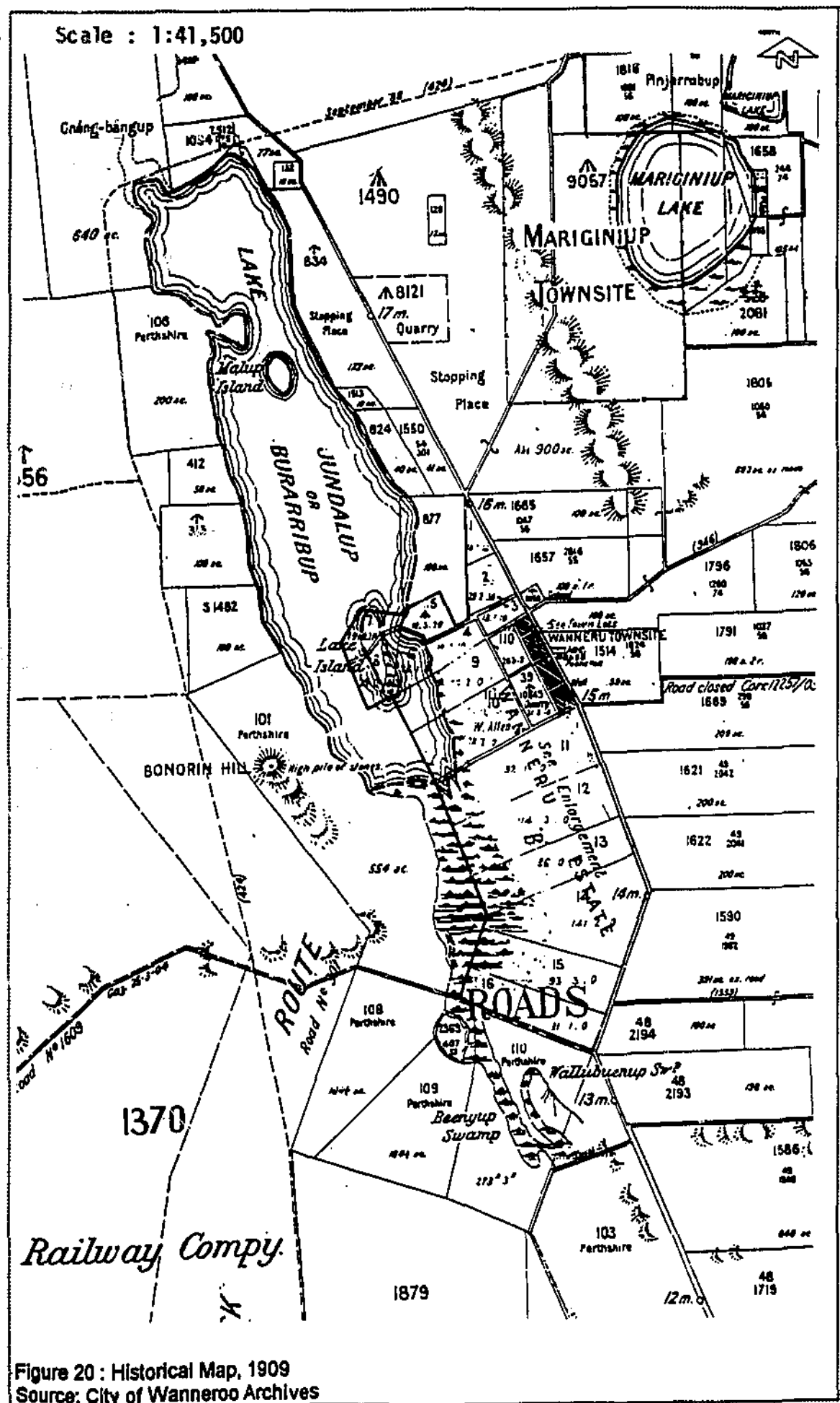
The map, Perth Land Agency 1A/40, (Office of the Surveyor General, 1909) depicts the southern end of Lake Joondalup with a dotted line. This area is covered with symbols suggesting reeds and water, except for the south-western section which is depicted as open water. Again the lake level can be deduced

as being approximately 16.6 A.H.D. Lake Cullalal, (Goollelal), is depicted as open water, and similarly, the reconstructed level is approximately 26.5 A.H.D. See Figure 20, p.78.

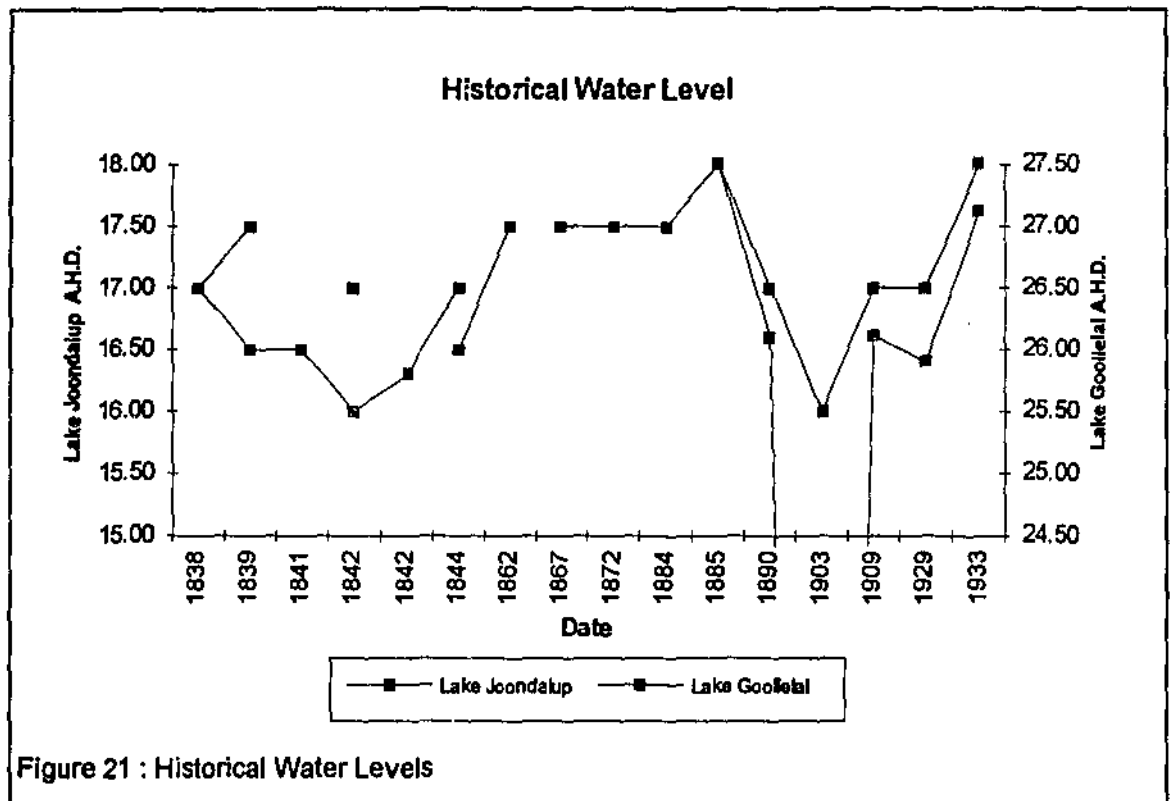
The map Perth L. O. (Department of Lands and Surveys, 1929) shows the southern end still covered in reeds and water, but the surface area has decreased since the 1909 map. An area on the south eastern bank has been excluded. This was, presumably, due to it being under cultivation by market gardeners at that time. Therefore, it would not have been appropriate to include the cultivated portion of the lake bed as part of the lake. The water levels are therefore calculated to be slightly lower than the 1909 recordings: 26.5 A.H.D. for Lake Goollelal, and 16.4 A.H.D. for Lake Joondalup.

A map (Shire of Wanneroo, 1933) gives the first actual water levels recorded for Lake Joondalup and Lake Goollelal. The date recorded is 1st May 1933 and the Lake Joondalup level 57.34. This figure represents feet above low water mark at Fremantle, which converts to 17.62 A.H.D. Lake Goollelal was recorded as 72.84 which converts to 27.44 A.H.D. using a formula provided by the Water Authority of Western Australia. The bench marks in this map are incorrect, it was necessary therefore to make adjustments for them within the formula.

Beenyup and Wallubuenup Swamps are annotated as a "running stream". (Shire of Wanneroo, 1933) This is the first reference to moving water being visible in the swamps. It is interpreted that the water levels of the lakes and swamps were high. This is consistent with observations made during the study period. The water levels of all wetlands are high and observations of running water in the swamps were first made in August this situation still existed when final observations were made in October.



By recording the dates and giving the approximated water levels where possible, the first vague suggestions of the seasonal cycle of drying and filling of the lakes begins to emerge. See Figure 21. It is worth noting that in the early period, except for limited clearing of vegetation, the lakes' water balance was undisturbed by human intervention.



4.2 Oral Histories

In an interview with Mr Nardo (Ned) Crisafulli, a long term resident who lived on farming land adjacent to the east bank of Lake Joondalup, recollections of the lake were discussed. It was revealed that the lake was noticeably affected by seasonal influences and variable levels were affected by the amount of rainfall received in a given year. Crisafulli, N. (personal communication, 1992), recalled that the lake level would rise gradually over two (2) or three (3) consecutive years of rainfall but after exceptionally heavy rain it "would come right up fast", flooding the vegetables planted by his father on the edge of the lake and the track to the north of the lake, (which is now Burns Beach Road).

Water would then overflow into the low lands, linking Lake Joondalup with Pauls' Swamp. Crisafulli, N. (personal communication, 1992), states that this occurred in about 1933 or 1934. The local residents, in order to stop the rising waters from flooding the market gardens, cleaned out the drainage channel that they had previously dug in the north-west side of Lake Joondalup. See *Figure 13, p.51*. The drainage channel is situated at a level of 17.5 A.H.D. Therefore, the lake would have had to rise to at least to 17.5 A.H.D. before the ditch would have been effective. Crisafulli, N. (personal communication, 1992) states this was one of three (3) separate occasions that the lake flooded before 1938 when he left the district for eight years. See *Plate 23*.



Plate 23 : Water Running into the Old Drainage Channel : The Water Level has Reached The Height Necessary for The Channel to be Effective, it is However Blocked with Debris.

In another interview, Crisafulli, S. (personal communication, 1992) revealed that he was present at the digging of the drainage ditch on the north-western edge of Lake Joondalup. Crisafulli, S. reported that an attempt to dig the drainage ditch, to help control the rising water, had been carried out a year or two before the 1933 attempt, (which was done with the assistance of the

Wanneroo Drainage Board). Supporting written information was obtained from the City of Wanneroo Archives Store. Several pieces of correspondence deal with the request for the channel to be dug, the survey of the lake, and a levy imposed on local residents to cover the costs of this work. The high water level at the time was the reason for the requested drain.

Crisafulli, N. (personal communication, 1992) also recalls chasing swampheens, (*Porphyrio porphyrio*) around the mud flats, when the southern end of the lake dried out and catching kangaroos (*Macropus canguru*) that had become bogged in the mud trying to cross the lake. The dry spell, he suggests, was around 1928 or 1929. Field work conducted throughout the course of this study testifies to the lower water levels. Note submerged fence in *Plate 24*.



Plate 24 : Submerged Fence Posts in the Southern Section of Lake Joondalup. A good indication of historically low water levels.

Similarly dead paperbark stands in the north-west section and south-west section of Lake Joondalup attest to more recent high water levels. A sustained

rise in water level flooding the paperbarks causes them to die. This must have happened in more recent times otherwise they would have rotted away.

Crissafulli, N. (personal Communication, 1992) when asked about the fence posts asserted that they were installed to keep the cows from the dairies on the western side from eating the vegetables when they wandered across the lake bed in dry seasons.

It can therefore be deduced from the information provided by Crisafulli, N. (personal communication, 1992), that the lake levels fluctuated over the period 1921 to 1938 between a high of 17.5 + A.H.D. and a low of 16.6 A.H.D. This cycle occurred three times making it two (2) to three (3) years between high and low points.

The interview with Mr Santos Crisafulli reinforced the views of his younger brother. Crisafulli, S. (personal communication, 1992), advised that he had been farming the banks of Lake Joondalup most of his life and therefore had carefully watched the rise and fall of the water level. The water level directly affected the amount of vegetables that could be planted. Crisafulli, S. stated that, the water would gradually rise over a period of two (2) to three (3) years, peak, and then gradually drop over a period of two (2) to three (3) years, bottom out and then this cycle would be repeated. These fluctuations in lake levels he suggests occurred quite independently of the regular seasonal cycle of drying and filling. This was a long term cycle that he had observed over more than seventy years. Crisafulli, S. believes this cycle follows the rainfall pattern of the area. A series of wet winters would cause the lake levels to peak and a series of dry winters would cause the lake to dry up.

Crisafulli, S. (personal communication, 1992), asserts that the water levels have been both dryer and higher in the past than current records reveal. That in fact "its been much higher in past seasons, it would cover half the block, up

almost as far as the shed, in '52 or '53 it was really high ... the highest I've ever seen it." It was possible with the use of a bathymetric map and a contour map to work out that in order to reach the point indicated by Mr S. Crisafulli the water would have to be between 17.8 A.H.D. and 18.0 A.H.D. The middle point of 17.9 A.H.D. has been taken as an approximate measure of the lake level of the time and used accordingly.

The late twenties, Crisafulli, S. (personal communication, 1992), reports were very dry, with horses and kangaroos getting stuck in the mud as they moved down to the lake in search of water. "The horses would sink up to their necks". Crisafulli, S. indicated that 1959 was the driest year in his recollection. It was possible to walk across the lake without getting bogged, which his son Mr Gerrard Crisafulli, had done. Crisafulli, G. states that "you had to be careful where you went as there were still very boggy bits but generally you'd only sink to mid shin". Crisafulli, G. & Van Kleef, M. (nee Crisafulli) (personal communication, 1992) both confirmed their father's opinion of a long term trend incorporating the wet and dry years of rainfall. They suggested that the lake never completely dried out, as natural springs kept some spots wet. This, it can be inferred, is where the ground-water table was higher than the lake bottom, causing pools of water to remain in the lake's deepest areas. An approximate water level for this period would be 15.6 A.H.D.

Mr F. W. (Bill) Duffy, a long term farming resident on the eastern edge of Wallubuenup Swamp, also provided information. Duffy (personal communication, 1992) revealed that, in the years that he went to the Wanneroo school, the children would go down to Lake Island and dive off the fence posts into the water. Duffy recalls doing this regularly in warm weather between 1916 and 1921. This period, Duffy states must have been a wet one as the fence posts were underwater during some of the summer when they swam in the lake.

It is noted that Chambers (1991, p.20) states that "during the summer months, Mr Hunter would take the boys down a track to the lake for a midday swim."

The water would generally be about six inches (0.1524m) below the top of the fence post, as recalled by Duffy, (personal communication, 1992). This indicates a summer water level for this period of approximately 17.44 A.H.D. The figure was arrived at by measuring in the field the present depth to the top of the fully submerged fence posts (0.22m). The calculation was completed by adding the six inches (0.1524m) and subtracting the whole from the current water level of 17.81.

Duffy, (personal communication, 1992) also recalled duck shooting on Lake Goollelal and Lake Joondalup between 1922 and 1924. The lakes, he asserts, were also full then as he had to take his dog to swim out and get the ducks. He indicated that in 1932 the main drain on the adjoining property overflowed due to the water level being so high; the next year he claimed it was high but below the level of the previous year. This suggests that the 1932 water levels were in excess of the recorded levels in 1933 of 17.62 A.H.D. for Lake Joondalup, and 27.44 A.H.D. for Lake Goollelal.

Duffy, (personal communication, 1992), related his recollections as the postman in the area, he travelled often around the lakes and clearly remembers Lake Joondalup being very dry in 1942. The entire bottom end, he recalled, was dry. This would represent a water level of approximately 16.00 A.H.D.

In conclusion, Duffy (personal communication, 1992), alleges that the water level rose in about 1919, and has rarely gone down since that period. He contends that the period of wet years is by far greater than the number of dry years.

4.3 Aerial Photography

Aerial photographs of the study area were limited between 1942 and 1955.

Aerial photography commenced in 1942, both Lake Joondalup and Lake Goollelal were photographed in this year. With the use of magnification, a planimeter and many current aerial photographs with known water levels, an approximate water level for Lake Joondalup of 16.0 A.H.D., and 26.4 A.H.D. for Lake Goollelal was calculated. The 1942 aerial photograph depicts the surface water contained within Lake Joondalup as covering a smaller area than in any other aerial photograph available. This reinforces Mr B. Duffy's assertion that the lake was very dry that year.

A 1953 aerial photograph was also used to calculate the water level of Lake Joondalup only, as water level data was available for Lake Goollelal at this time. The level calculated for Lake Joondalup was approximately 17.00 A.H.D. The lake's area was very close to its area depicted in the 1985 and 1992 aerial photographs.

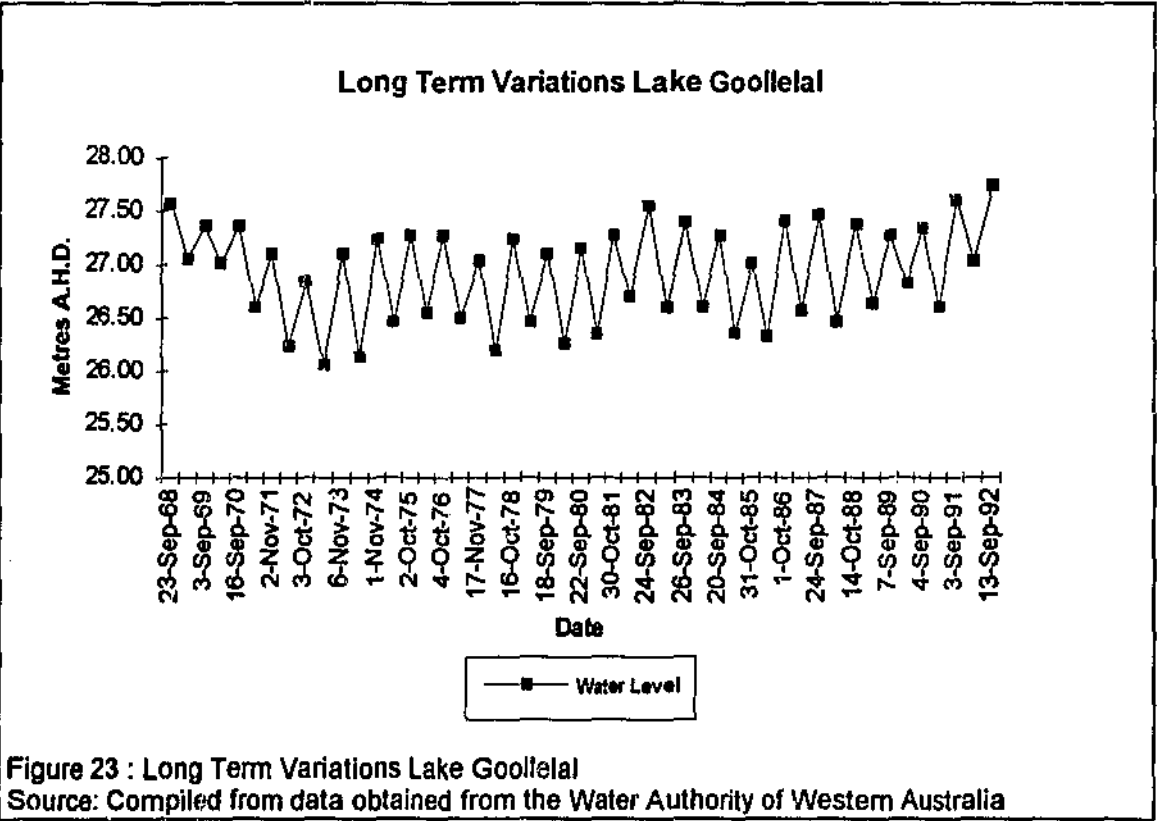
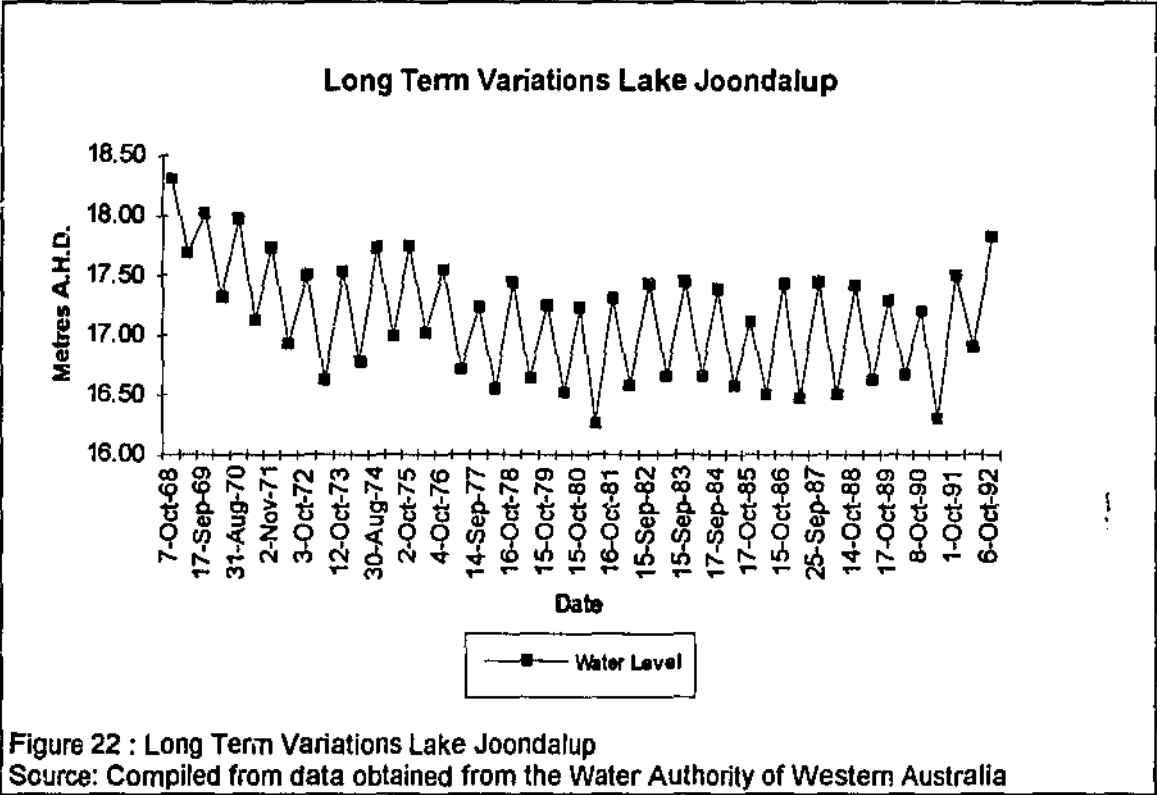
There were no other aerial photographs of suitable dates to fill in gaps in the reconstruction of historic water levels. Therefore, the remainder of the reconstruction of water levels is primarily concerned with data from the Western Australian Water Authority data and data collected during field trips to the study area.

4.4 Seasonal Variations

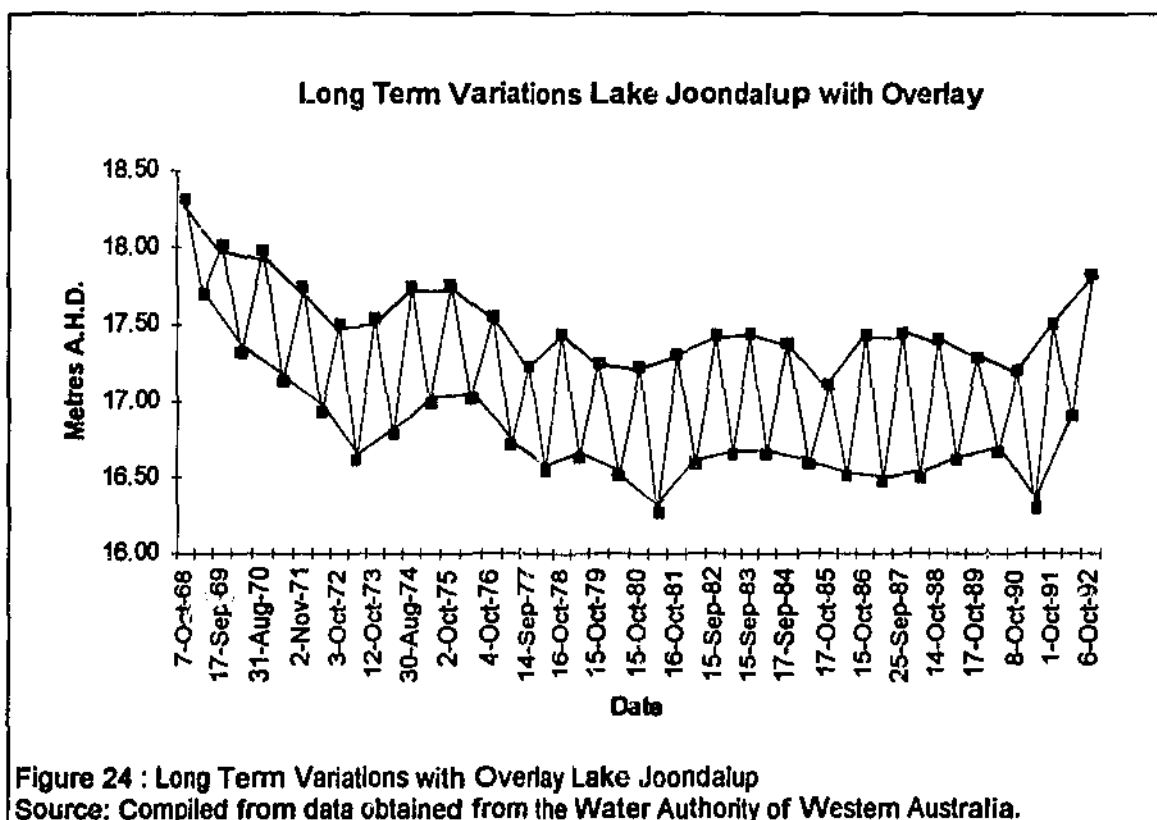
There are quite large seasonal changes in the water table of the Gnangara Mound between summer and winter. On the coastal strip, however, the seasonal change is in the range of half a metre. (Allen, 1981, p.75).

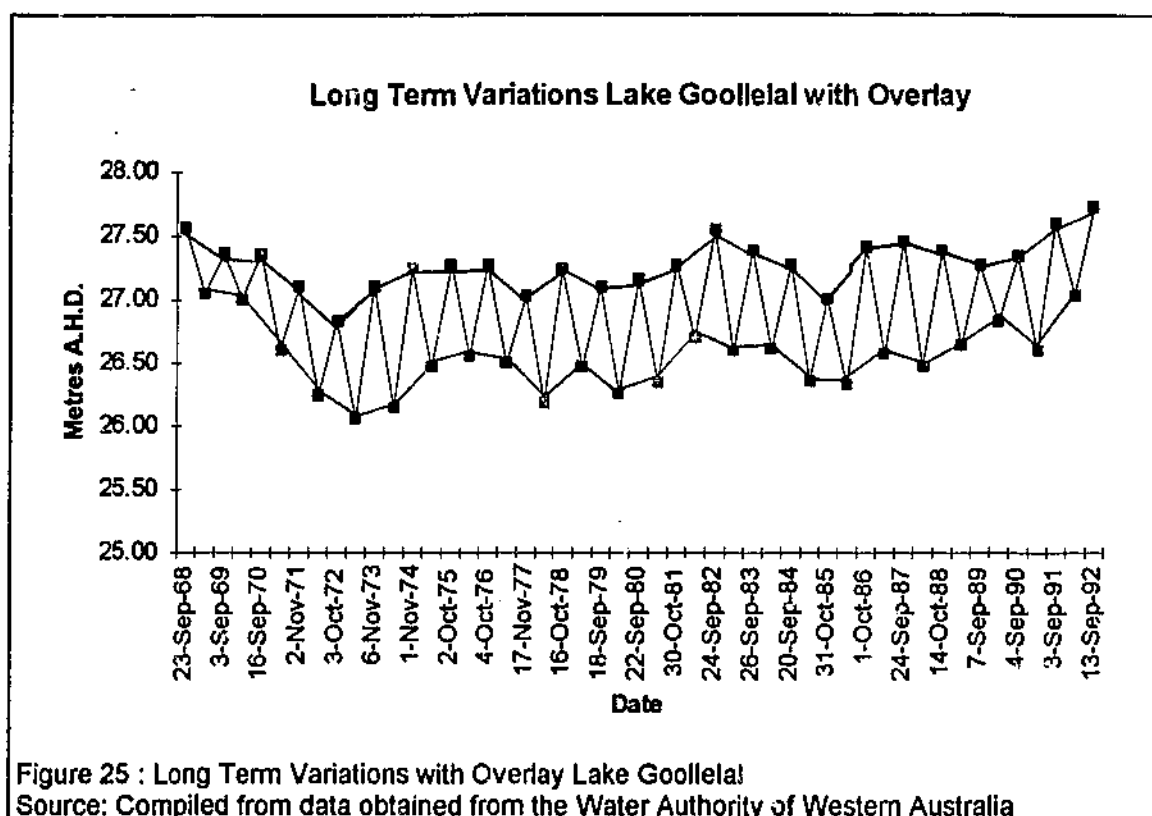
Therefore, the lakes are not an exact expression of the water table as the lake depths may regularly vary as much as one (1) metre or more over a period of a few months.

The long term variation of the lakes is detailed in *Figures 22 and 23, p.86*. This demonstrates the cyclic pattern not only of the seasons but also a long term variation that shows the lake levels slowly decreasing, and then slowly increasing in recent years.



This pattern is more apparent in *Figures 24 and 25, p. 88*, which depict the long term minimum and maximum lake levels of Lake Goollelal and Lake Joondalup. An overlay links all maximum water levels and all minimum water levels emphasising the cycles of increasing and decreasing cycles of lake level. The standard deviation for this data was calculated using Statgraphics Execustat R, It was found with a 95% confidence level that the mean water level for Lake Joondalup was 17.14 and the standard deviation was 0.500 metre. It can therefore be stated that in any given year, the water level for Lake Joondalup will fluctuate between 0.417 and 0.625 of a metre. Lake Goollelal was similarly analysed and the mean water level was 26.92 A.H.D. and the standard deviation was 0.455 metre. In any given year the water level of Lake Goollelal will vary by between 0.380 and 0.569 of a metre . Therefore, if the starting point is high, then the level for the following year is likely to be higher and vice versa.

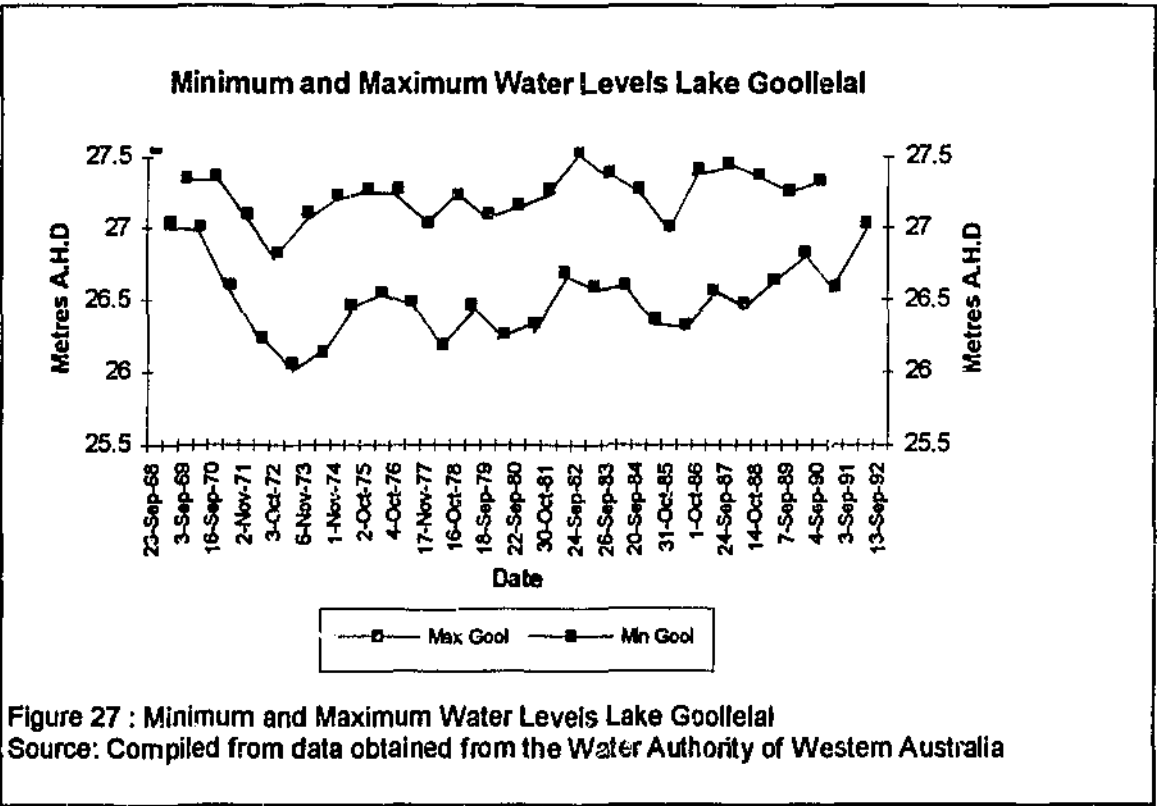
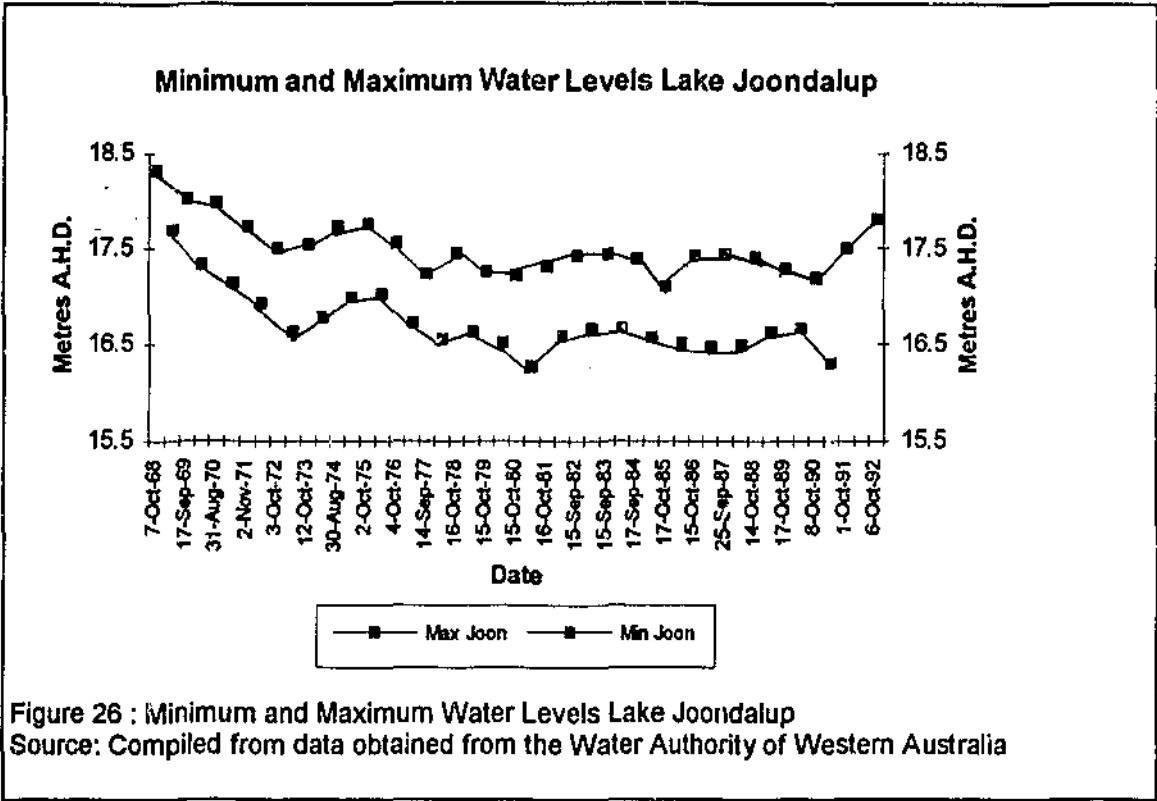




Lake Joondalup, over the period 1968 to 1992, has varied between 18.312 A.H.D. (on 7-10-68) to 16.470 A.H.D. on (2-4-87). This represents a long term variation between the recorded high and low water levels of nearly 2 metres.

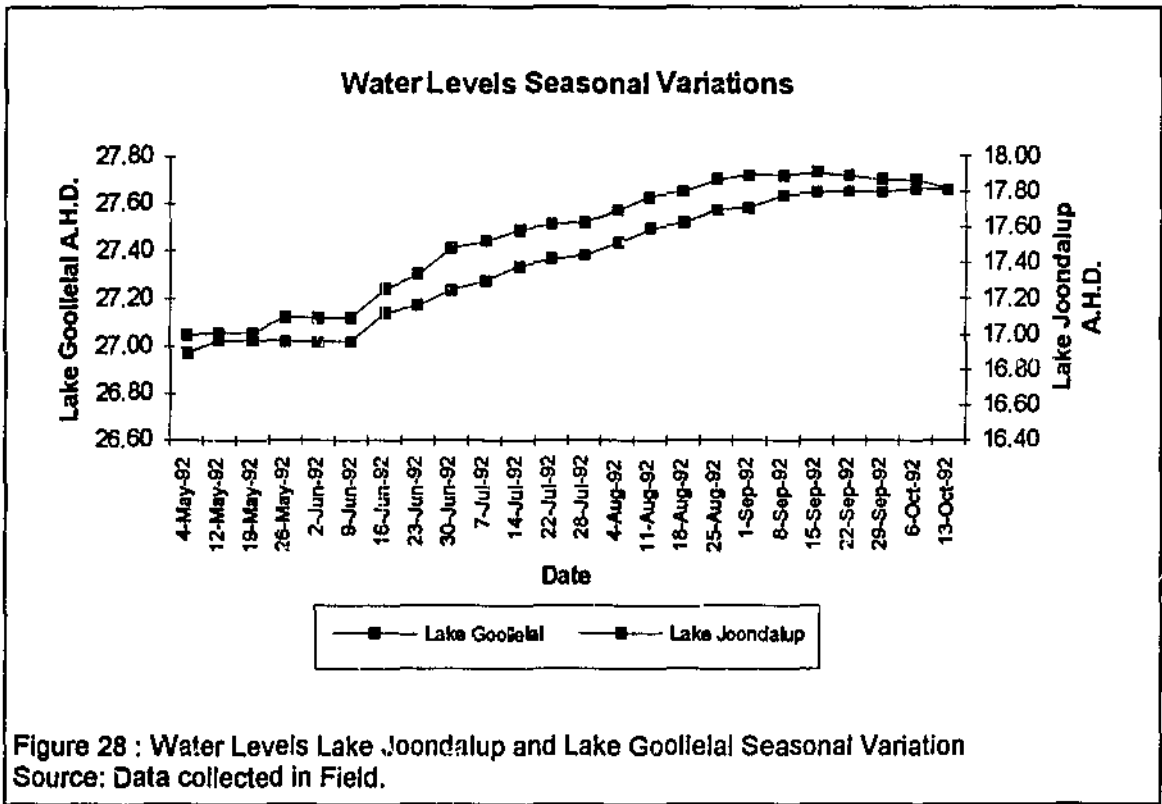
Lake Goollelal over the period 1962 to 1992 has varied between 27.603 (on 6-10-64) to 26.057 (on 28-5-73) to its highest ever recorded 27.740 (on 13-9-92). This represents a long term variation between record high and low of 1.107 metres and Goollelal is currently rising, therefore this figure could be exceeded shortly.

Figures 26 and 27, p.89 also demonstrate the gradual decline in water levels of both lakes over a period of two (2) or three (3) years in maximum and minimum water levels followed by the gradual increase over a period of two (2) or three (3) years. This reinforces the pattern described by the Crisafulli's.



4.5 Current Measurements

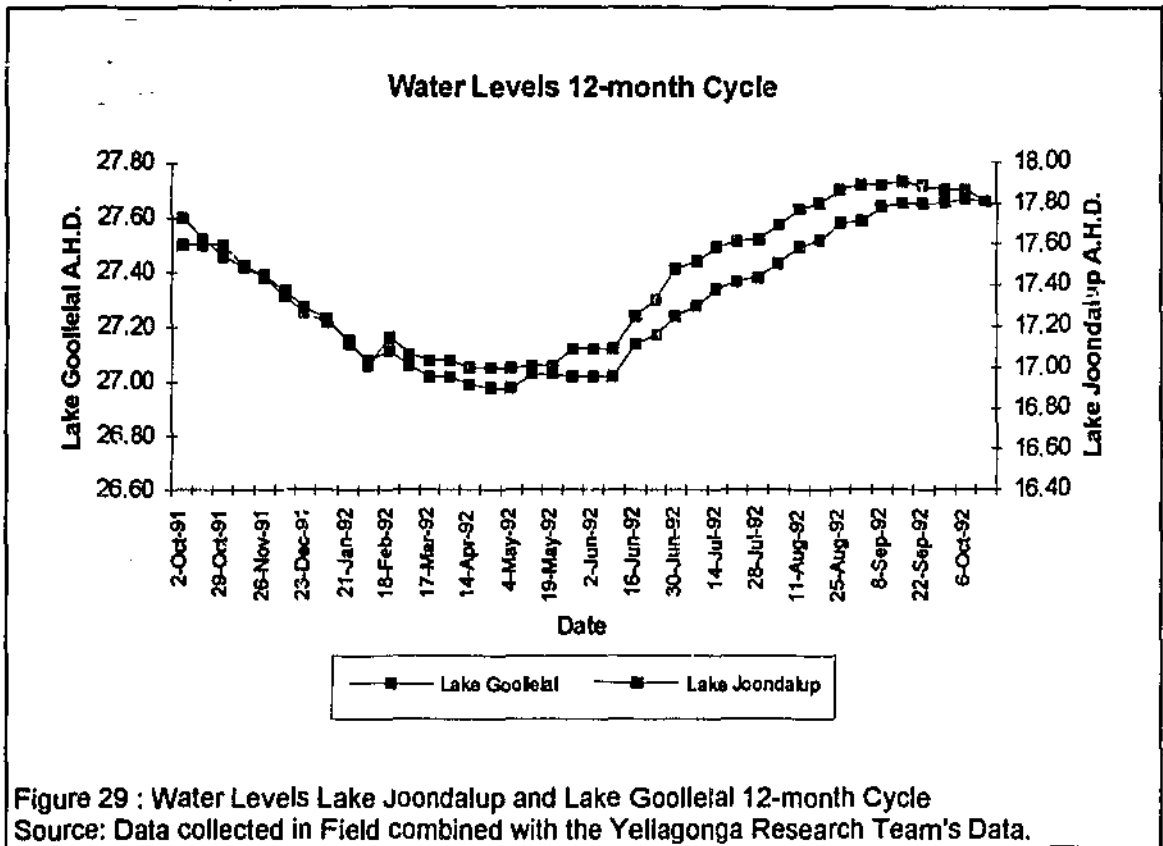
Lake level data during the course of this study was initially recorded weekly, beginning in May 1992. There was only a small change in levels over this period, probably due to the mild weather experienced. With the onset of heavy winter rains and lake level increases to near record levels, recording was commenced on a daily basis, in September 1992. *Figure 28*, represents the seasonal variation in water levels over the period of the study.



By adding data collected prior to this by researchers from Edith Cowan University, (Yellagonga Research Project) the full twelve (12) month cycle can be seen in *Figure 29*, p.91.

Figure 29, clearly demonstrates the link between Lake Goollelal and Lake Joondalup. Both lakes, although at differing A.H.D., experience water level fluctuations that vary concurrently. The lakes' water levels progressively decline from October through to early May when they begin to rise again. Lake levels rose throughout the course of this study. Current measurements are

very high and seem to be the beginning of an upward trend of rising lake levels as seen in the past.



Monthly water level data for Lake Goollelal and Lake Joondalup was evaluated using Statgraphics Execustat R. The two sets of lake level data are highly correlated at the 5% level of significance, with a correlation coefficient of 0.9801 and a P value score of 0.000. This very high correlation reinforces the belief that they are a directly linked wetland system. Disproving any theory that the road works, resulting in the construction of Hocking Road, Whitfords Avenue, Duffy Road and Ocean Reef Road, have substantially altered this situation.

By combining the water level data calculated in the historical, oral history and aerial photograph sections with the current Water Authority of Western Australia data and field data the fully reconstructed water levels for Lakes Joondalup and Goollelal can be seen in *Figure 30, p.92*.

Reconstruction of Water Levels 1838-1992

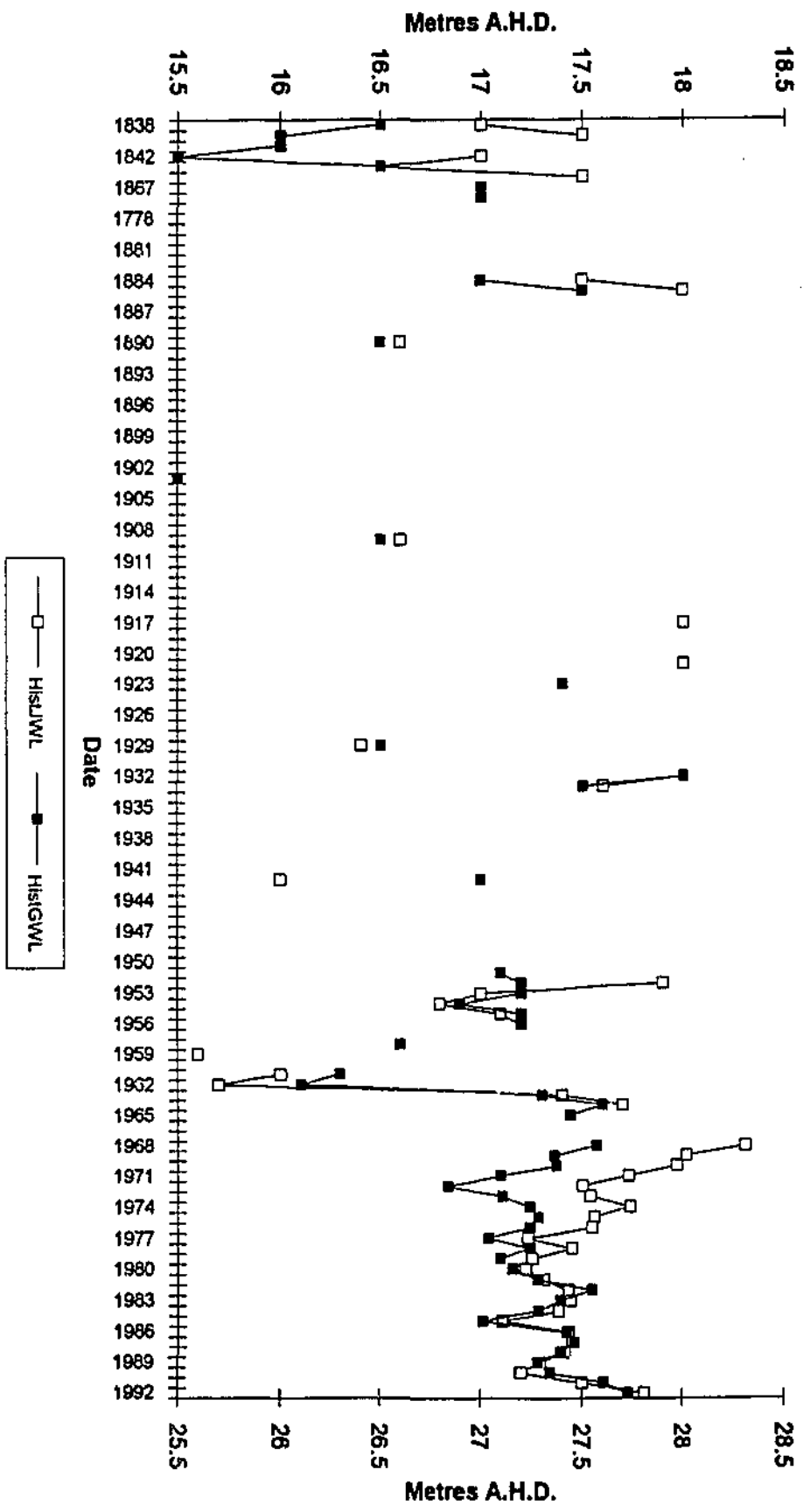


Figure 30 : Graph of Water Level Reconstruction

CHAPTER 5 : THE RELATIONSHIP OF LAKE LEVELS TO CLIMATIC DATA

5.1 Wanneroo Data verses Perth Data

Rainfall records for the area of Wanneroo are sporadic. Records began to be taken by the the Lands and Survey Department in 1876 and continued, with several missing years, until 1930. Records re-commenced in 1963 when the Bureau of Meteorology was established and are currently still being taken. There are, however, several sets of missing data. It was, therefore, necessary to demonstrate a correlation between Wanneroo data and Perth Regional Office Data. The data was evaluated using, the statistical computer software Statgraphics Execustat R. The Perth Regional Office data is well correlated with the Wanneroo station data at the 5% level of significance, with a correlation coefficient for the two sets of data of 0.9631 and a P value of 0.000. Therefore, the Perth data was used where no Wanneroo data was available.

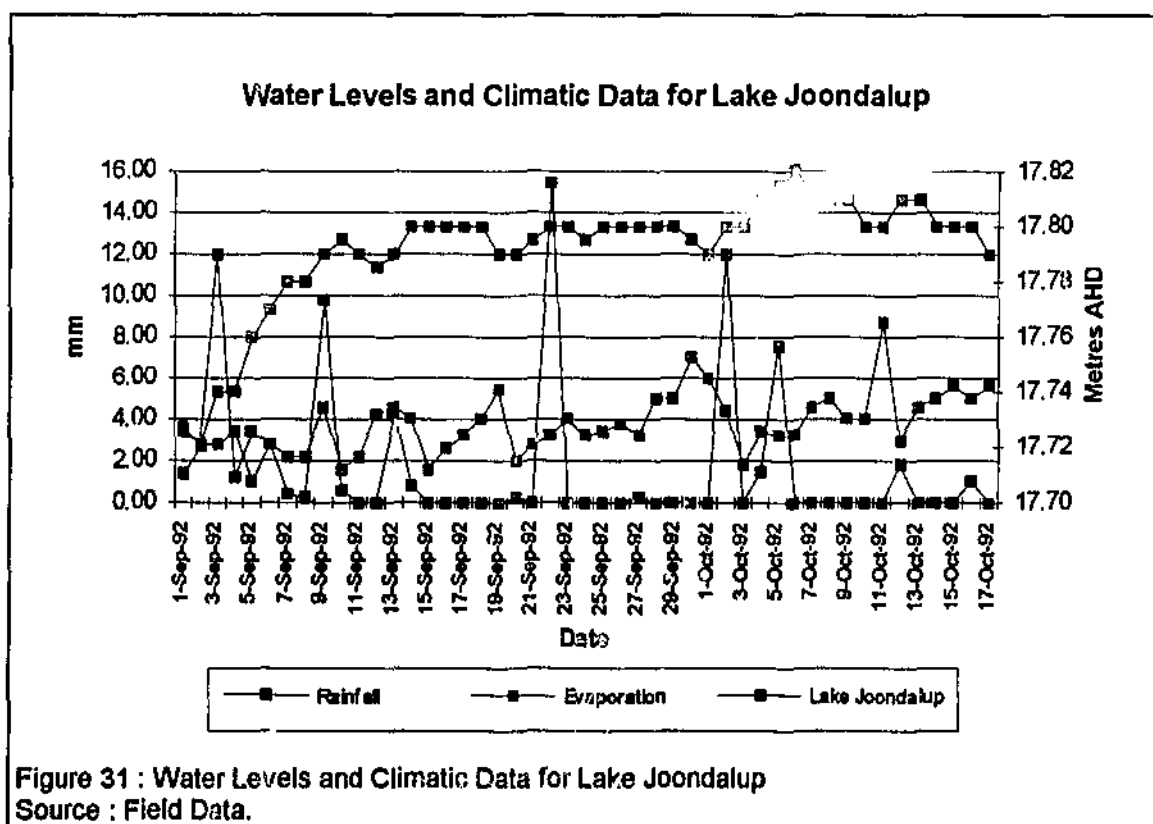
Evaporation measurements are not taken at Wanneroo. Therefore, a Class "A" Evaporation Pan was set up in Joondalup. The results from this pan were correlated with the Bureau data recorded at Perth Airport. On the basis of the recordings no correlation could be demonstrated. This is possibly due to the less than perfect Joondalup Pan location. For security it was necessary to position the Pan in a locked enclosure. The enclosure, however, experiences afternoon shade which would affect the measurements. Due to this lack of reliability, it was decided that the Perth would be used.

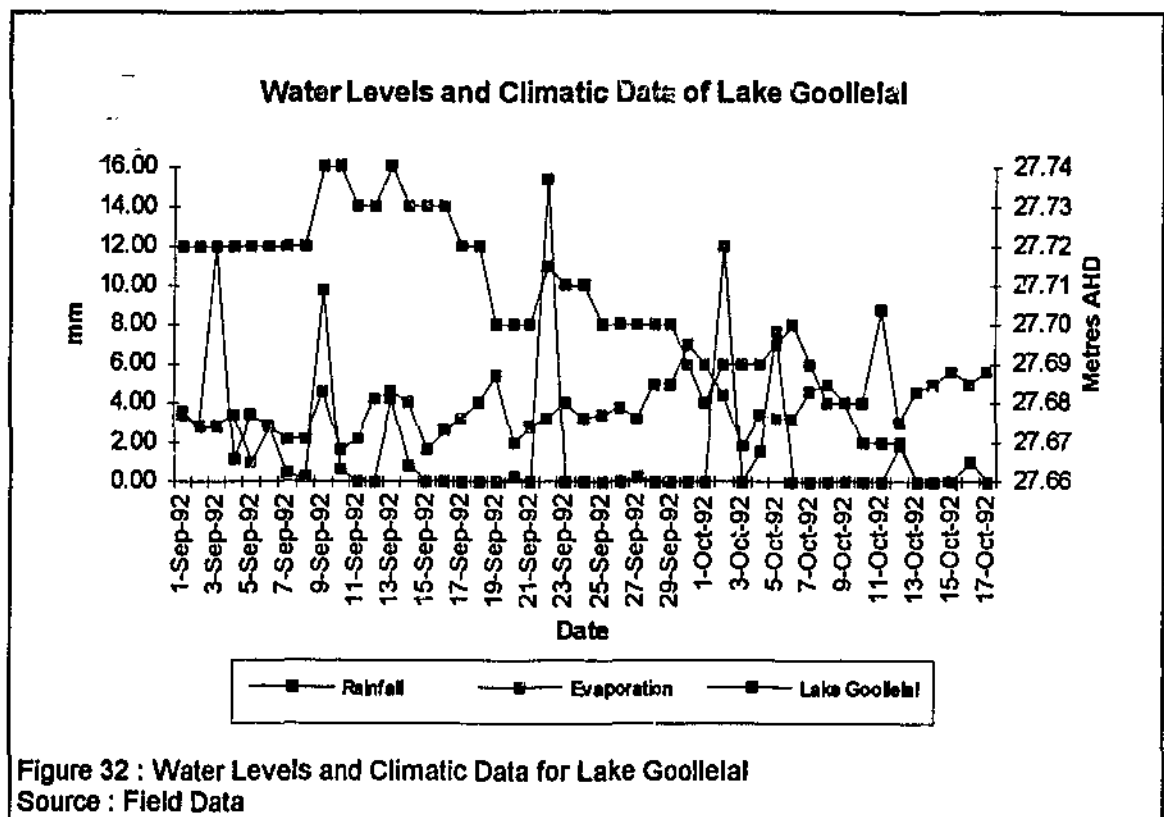
The two maximum recorded annual rainfall totals for Perth were in 1945 with 1340 mm and 1926 with 1253 mm. For Wanneroo no records exist between 1930 & 1963, however, the maximum reading in 1926 was 1283 mm. The two minimum recorded annual rainfall levels in Perth were 509 mm in 1940 and 515 mm in 1914, with Wanneroo receiving 472 mm in 1914. These examples demonstrate the close correlation of rainfall levels between the two centres.

In Perth about 90% of rain falls between April and October, but rainfall only exceeds evaporation between May and August, for the rest of the year there is a rainfall deficit, with evaporation far exceeding rainfall. It seems likely therefore, that evaporation would have a much greater affect on the water levels of the lakes than rainfall for most of the year, especially considering there large surface area and shallow depth. This emphasises the importance of heavy winter rainfall in determining the years where increased water levels are experienced and reinforces the assertions made in the oral history interviews.

5.2 Degree of Correlation between Lake Levels and Climatic Data -Short Term

Lake levels, evaporation and rainfall were measured daily from the 1 September, 1992, until the 17 October 1992. The results of this daily monitoring for Lake Joondalup are graphed in *Figure 31* and Lake Goollelal in *Figure 32*, p.95.





The September to October data emphasises the affect rainfall has on lake water levels and the minimised affect of evaporation. The statistical analysis showed no significant correlation between rainfall, evaporation and water level for Lake Joondalup. For Lake Goollelal only evaporation and water level was found to be significantly correlated at the 5% level with a correlation coefficient of -0.5347.

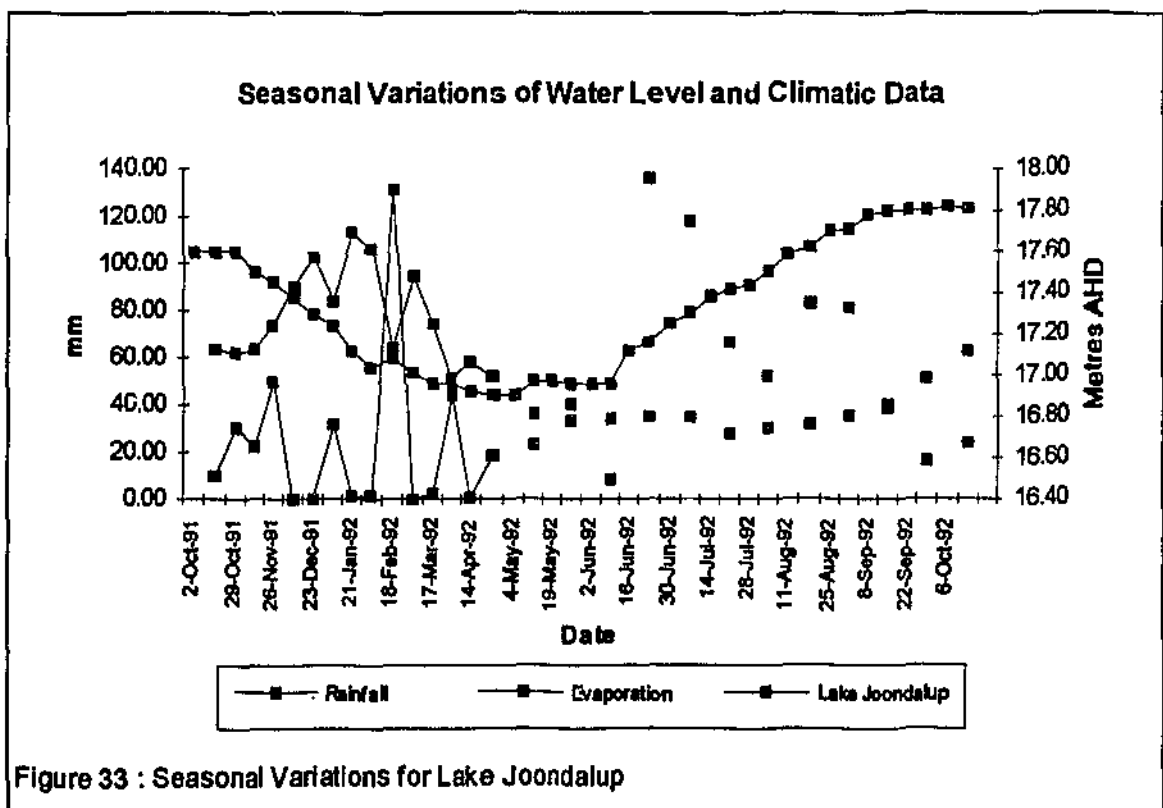
This demonstrates that on a day to day basis, from 1 September 1992 until 17 October 1992, rainfall had no immediate affect on the water level of either Lake Joondalup or Lake Goollelal. Evaporation also had no immediate affect on Lake Joondalup, and only a minor affect on Lake Goollelal. This is best explained by the fact that the volume of water is of such a magnitude that isolated episodes of small amounts of rain are unlikely to cause a discernable increase in depth. Similarly the affects of evaporation would need to be

experienced over a considerable length of time before a noticeable reduction in lake levels would be recorded.

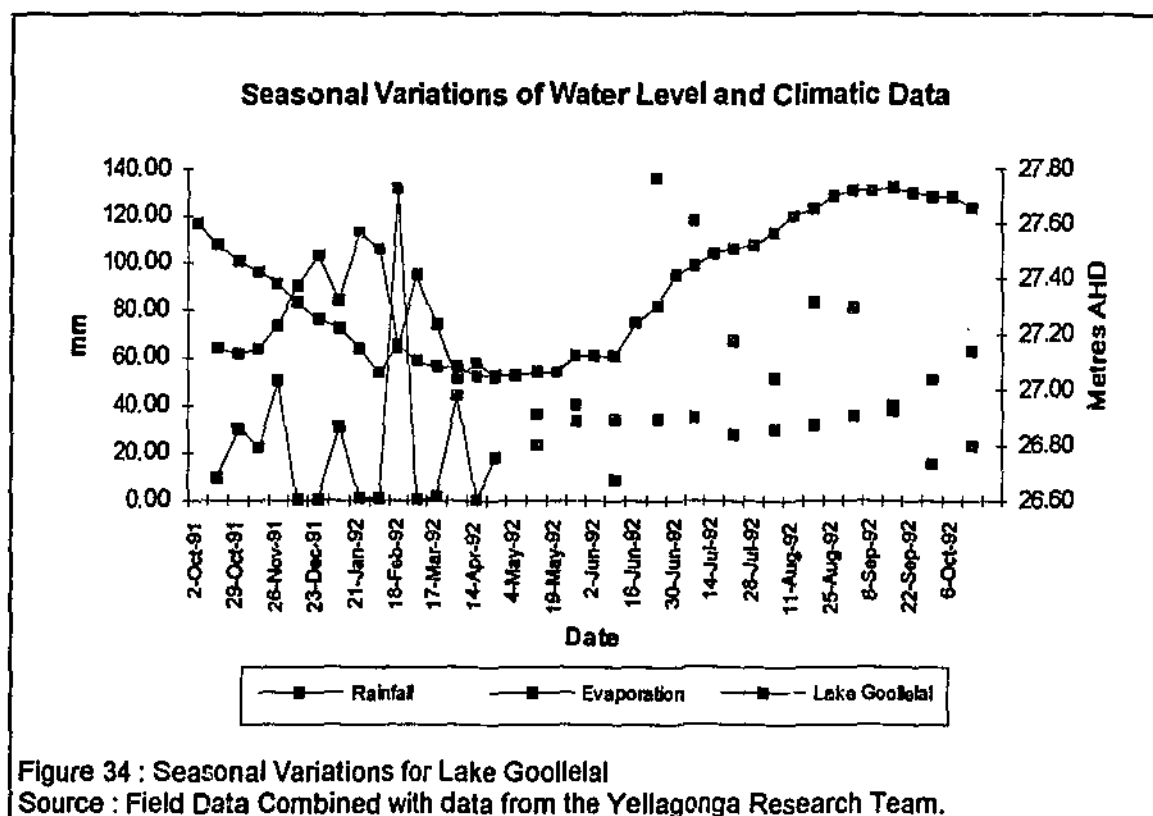
5.3 Degree of Correlation Between Lake Levels and Climatic Data - Seasonal

Lake levels, evaporation and rainfall have been monitored on a weekly basis throughout the course of this study. However, in order to obtain the full seasonal cycle it was necessary to obtain water level, evaporation and rainfall results for several months preceding the commencement of this study.

Daily recordings of evaporation and rainfall data were obtained from the Bureau of Meteorology. The water level data was only available on a fortnightly basis. This data was obtained from the Yellagonga Research Team at Edith Cowan University. All records are, therefore, only able to be compared on a fortnightly basis due to the lack of water level data available. *Figures 33 and 34, p.97.* are a graphical representation of the fortnightly water level, rainfall and evaporation data for Lake Joondalup and Lake Goollelal respectively, over the last twelve month cycle.



As with the daily cycle no direct correlation could be established between rainfall, evaporation and water level for Lake Joondalup, and only a small significant negative correlation at the 5% level could be established between evaporation and water level (-0.4064) for Lake Goollelal. No correlation between rainfall and water level for Lake Goollelal could be established.

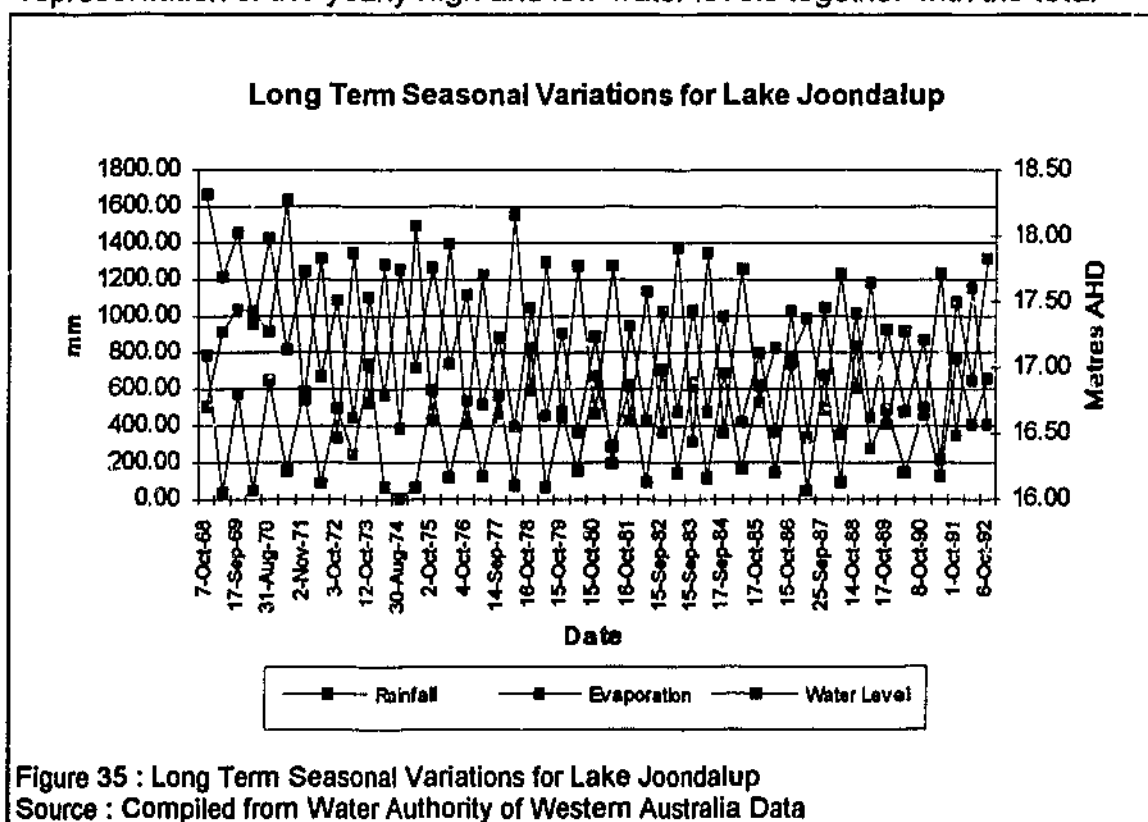


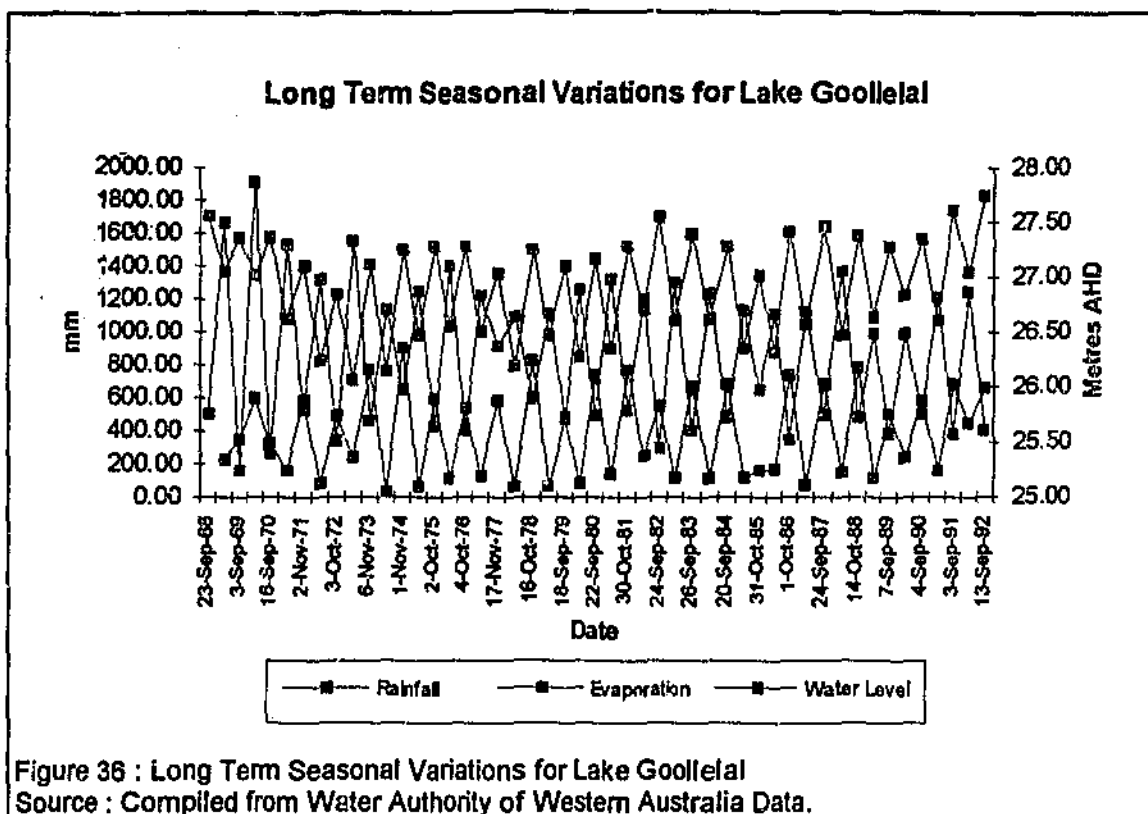
The seasonal cycle for each month of each separate year from 1971 until 1991 was analysed to establish whether rainfall, evaporation and water level of the lakes had a correlation in past years. A correlation was established between rainfall and the water level of Lake Goollelal only in 1971. This set of data was found to be significantly correlated at the 5% level with a correlation coefficient of 0.7198 and a P value of 0.0189. No other correlation was found in any other year, whether particularly wet or dry. However, all sets of data years displayed a high level of negative correlation between evaporation and rainfall data.

This suggests that climatic data has little or no affect on water levels on a monthly, fortnightly or daily basis and reinforces the view that the lake level shifts are a cyclic phenomenon occurring over several years.

5.4 Degree of Correlation Between Lake Levels and Climatic Data - Long Term Seasonal Variations

Lake levels, evaporation and rainfall data have been obtained and analysed overing a 24-year period from 1968 to the October 1992. Monthly evaporation and rainfall data dating back to 1897 were obtained from the Bureau of Metaorology. The water level data was obtained from the Western Australian Water Authority and was only available on a monthly basis dating back to 1968. All records were compared on a monthly basis, beginning in 1968, when water level data also commenced. *Figure 35 and Figure 36, p.99* is a graphical representation of the yearly high and low water levels together with the total





amount of rainfall and evaporation recorded between these dates for Lake Joondalup and Lake Goollelal respectively. The graphs demonstrate how the rainfall and evaporation affect the water level in a collective way over a longer period of time.

Statistical analysis, for Lake Joondalup, showed that rainfall and lake level were significantly correlated at the 5% level with a correlation coefficient of 0.6756, and evaporation and lake level were significantly correlated at the 5% level with a correlation coefficient of -0.6713.

It was found for Lake Goollelal that rainfall and lake level were significantly correlated at the 5% level with a correlation coefficient of 0.8475 and evaporation and lake level were significantly correlated at the 5% level with a correlation coefficient of -0.7686.

This has been interpreted as rainfall having a positive cumulative affect on the water level of both lakes, (ie. when rainfall is high the lake level increases).

Evaporation, however, has a negative cumulative affect on the lake level, (ie. when evaporation is high the lake level decreases). This relationship was tested statistically. The monthly rainfall and evaporation data since 1971 was evaluated. The two sets of data are significantly correlated at the 5% level with a correlation coefficient of -0.7789 and a P value of 0.00. This demonstrates clearly the inverse relationship between rainfall and evaporation.

5.5 Conclusions on Water Level and Climatic Data Correlation.

It is concluded that the long term seasonal water level variations are significantly correlated to the climatic data, and that the short term daily, fortnightly and monthly water levels are not correlated to climatic data. This reinforces the theory that it is the seasonal climatic conditions that affect the lake level. It is the cumulative affect of either summer or winter that produces a discernable change in lake levels rather than events limited to a time frame of one (1) month or less. Heavy rains in a wet season combined with decreased evaporation causes the level to rise. A dry season with high evaporation and low rainfall causes the level to drop.

To establish whether this trend is changing, the data from the long term seasonal variations was divided into two (2) sections. The first pre 1975, which was representative of Wanneroo as a rural community with a population of >10000, and the second, post 1975 which encompasses the period of rapid urbanisation within the catchment area. The 1992 population figure for the City of Wanneroo is 189370. (Bureau of Statistics and City of Wanneroo, Personal Communication, 1992)

A significant correlation at the 5% level between Lake Joondalup water levels and rainfall and evaporation for the period 7 October 1968 to 2 October 1975 was found. A correlation coefficient for evaporation and water level of -0.6889

with a P value of 0.0045 was recorded. For rainfall and water level, a correlation coefficient of 0.6532 with a P value of 0.0083 was established.

It is significant that the period 5 April 1975 to 6 Oct 1992 showed a marked increase in these correlation coefficients. A significant correlation was also established at the 5% level, this time however, a correlation coefficient for evaporation and water level of -0.8498 with a P value of 0.0000 was recorded. Rainfall and water level produced a correlation coefficient of 0.8889 with a P value of 0.0000.

The same changing trend was found for Lake Goollelal. A significant correlation at the 5% level between Lake Goollelal water levels and rainfall and evaporation for the period 23 September 1968 to 2 October 1975 was found. A correlation coefficient for evaporation and water level of -0.6084 with a P value of 0.0161 was established and for rainfall and water level a correlation coefficient of 0.7236 with a P value of 0.0023 was established.

The period 5 April 1975 to 6 Oct 1992 also produced a significant correlation at the 5% level between Lake Goollelal water levels and rainfall and evaporation. A correlation coefficient for evaporation and water level of -0.9006 with a P value of 0.000 was established and for rainfall and water level a correlation coefficient of 0.9083 with a P value of 0.0000 was established.

It can be deduced that the increased correlation between water levels of the lakes and climatic data is due to the increase in residential development in the study area. This is apparently resulting in increasing rainfall recharge through run-off and decreasing evapo-transpiration. To attempt to understand this change in the trend of the correlation between water level and climatic data, it is therefore necessary to examine land use changes.

CHAPTER 6 : RELATIONSHIP BETWEEN LAKE LEVELS AND THE HISTORICAL DEVELOPMENT OF THE CATCHMENT.

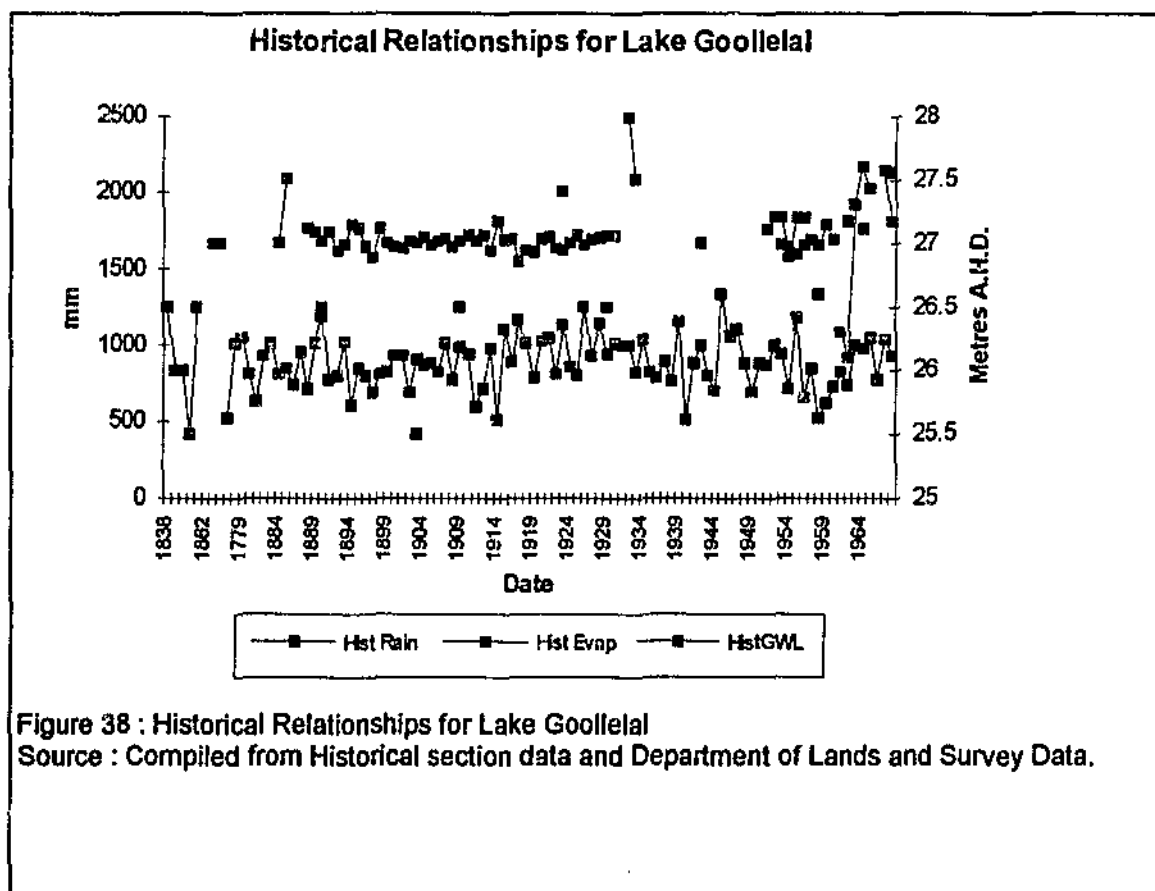
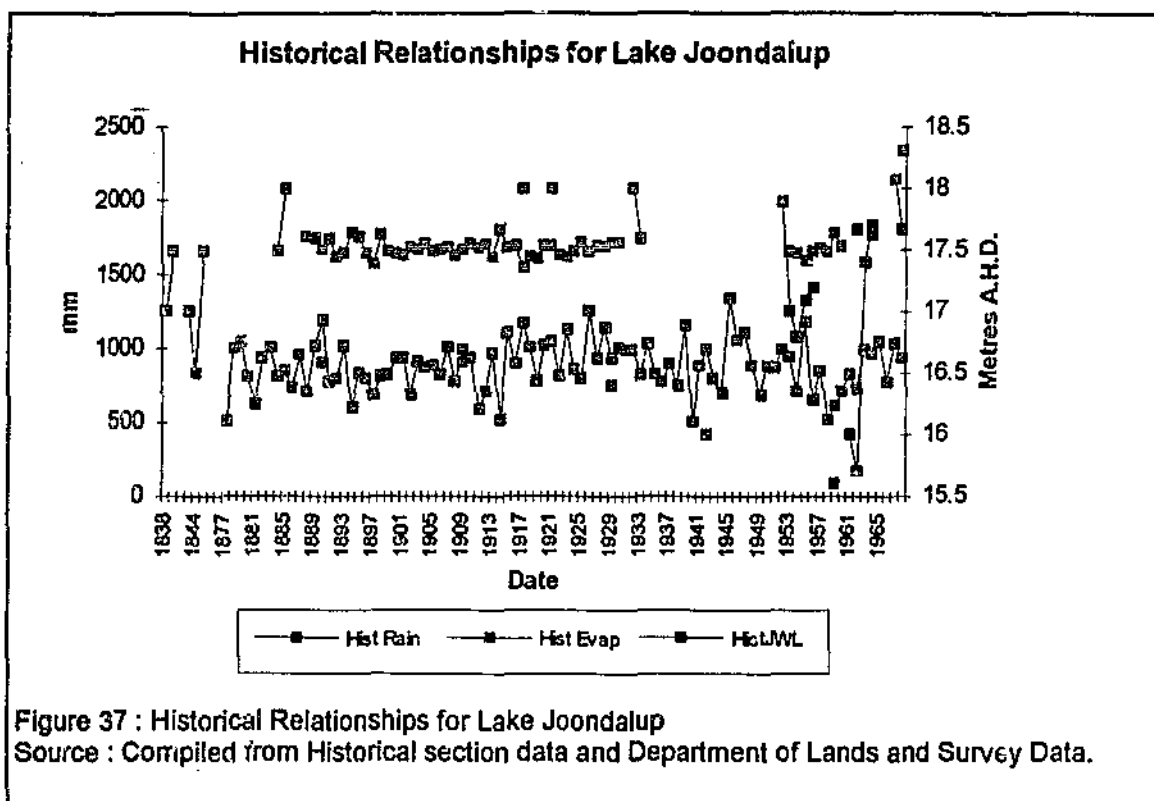
6.1 Prior to European Settlement.

It is apparent that prior to settlement of the area surrounding the wetlands that the water level of these wetlands fluctuated greatly. The lakes experienced the natural cycle of drying and filling undisturbed by human interference. The aboriginies used Lake Joondalup and Lake Goollelal as favoured camping areas, due to the prolific quantity of game available. Lake Joondalup was also used as a summer refuge, local aboriginies reported that even in times of drought it did not completely dry out. The lake became a valued source of fresh water in these times. The aboriginal life style caused little disturbance to the surrounding bushland and therefore the lake. Hunting and gathering were their means of acquiring food, they did not clear the land or plant crops.

(O'Connor, et al., 1989)

The fact that the lake levels experienced a cycle in tune with the weather is apparent from the viewing of the results of the water level reconstruction made in section 3.1 in conjunction with the climatic data available for the time. *Figure 37, p.103* depicts this relationship for Lake Joondalup and *Figure 38, p.103* for Lake Goollelal.

The historical water level data is significantly correlated with both rainfall and evaporation data at the 10% level. The correlation coefficient for rainfall and water level is 0.4209 with a P value of 0.0646 and for evaporation and water level a negative correlation coefficient of -0.5833 was obtained. No correlation was found between Lake Goollelal and rainfall or evaporation. This lack of correlation could be due to the limited amount of matching data available for the purpose of analysis. (ie only 16 sets)



6.2 History of Settlement.

The first land taken up in the area was around the southern section of Lake Joondalup in 1838, in a partnership, by Hodges, Connolly, Dobbins and Hester. Around the same time another partnership consisting of Rogers, Moore, Shenton and Jeffers also obtained land around Lake Joondalup. Neither group settled in the area, the land being used instead as a hunting retreat. (Chambers, 1991; Daniel & Cockman, 1979)

In 1844 land was granted, on the north-east shore of Lake Goollelal, to the Wesleyan Mission to establish an experimental farm to teach the aboriginals farming skills. The farm incorporated twenty three (23) hectares, of which six (6), had been cleared for farming by 1846. This was the beginning of the clearing of the natural vegetation surrounding the lake for crops and pastures that was to continue for more than a hundred years. The Native farm however did not last very long, by 1852 it had failed and the Mission moved to York. (Chambers, 1991; Daniel & Cockman, 1979)

Among the first settlers in the area were the Cockman family, who took up land to farm on the east shore of Wallubuenup Swamp, in 1852. By 1872 it was estimated that 60 families lived in the Wanneroo area, concentrated mostly around the shores of the numerous lakes in the area, including Lakes Joondalup and Goollelal. Due to the density of the bush, and lack of suitable equipment, clearing was limited. The region consisted mostly of dairy farms and small areas of vegetable growing. (Daniel & Cockman, 1979)

6.3 Market Gardens and Further Development of the Study Area.

This situation did not alter until about the early 1920s when many Italian migrant families moved into the area. With hard work they cleared and cultivated much of the land around the lakes transforming it into fertile

vegetable growing areas. The impact on the lake, however, was still not great, as there was no paved areas and no large scale clearing except for the strip around the lakes. This strip was mostly limited to the eastern shore of Lake Joondalup as the soils of the western shore were unsuitable for growing vegetables, and was used mainly for dairying which did not require as extensive clearing.

The population of the Wanneroo district grew very slowly in the first half of the century. By 1942 Wanneroo had only grown to 527 people who resided in 200 houses. There was no electricity and only 58.8 km of bitumen roads, and 32.6 km of block, limestone or dirt roads. (Daniel & Cockman, 1979) *Figure 39, p.106* depicts the small areas that had been cleared and utilised for rural activities. It can be concluded from this plan, (which was constructed from aerial photographs), that there was still little or no affect to the water balance of the Yellagonga Regional Park Wetlands.

In 1954 the population had reached 1299, five (5) years later in 1961 the population had increased by a scant 433 people to 1732. A further five (5) years added 705 people for a total of 2437 in 1966. (Australian Bureau of Statistics, 1954; 1961; 1966) See *figure 2, p.10*

Figure 40, p.107 depicts the development of rural properties that occurred over a twenty year period to 1965. Most of this expansion has taken place on the eastern side of the lakes. It is interesting to note that widespread residential development is still not apparent. Wanneroo in 1965 was very much a farming community.

LAKE AREA 1942

LEGEND

- MAIN ROADS
- PARK BOUNDARY
- URBAN AREA
- OPEN FOREST
Treet-Journal-Mori-Borussia
- LIGHT INDUSTRIAL
- SPECIAL RURAL
- JOONDALUP CITY
- SPECIAL RESIDENTIAL

NORTH



Scale : 1:40,000

Figure 39 : Land Use 1942

Source : Compiled from Aerial Photographs taken in 1942 of the area.

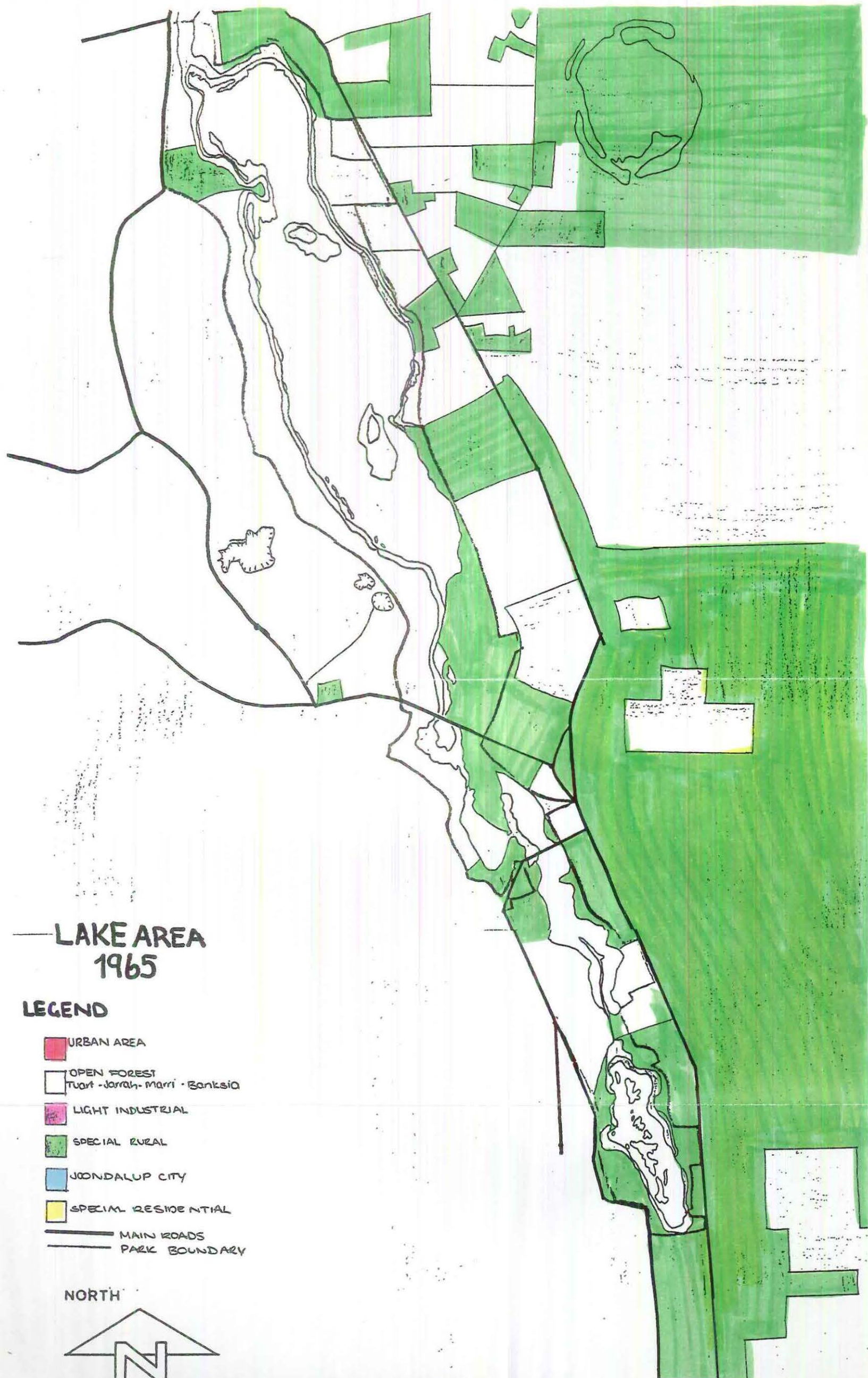


Figure 40 : Land Use 1965
Source : Compiled from Aerial Photograph taken in 1965 of the area.

6.4 Residential Development

The population of the Perth Statistical Division more than doubled between 1954 and 1971. It was, therefore, inevitable that some of these people would eventually find their way to the Wanneroo area. The first major residential development was begun in 1969. It added approximately 2000 dwellings and 6183 people to the area by 1971. Wanneroo, according to the 1971 Census had a population of 8620 people who resided in 2352 dwellings. (Australian Bureau of Statistics, 1954; 1971)

In the early 1970s saw the launching of the Corridor Plan for the Metropolitan Perth was implemented. In this scheme Joondalup was earmarked as a sub-regional centre, being the middle of the North-West Corridor. This encompassed the area north of Hepburn Avenue to the northern boundary of the Shire and west of Wanneroo Road. At this time there was still large amounts of bushland on the western side of the lakes and pastures and farm land on the eastern side. *See Figure 41, p.109.*

In 1975 the major residential subdivisions of Edgewater, on the western bank of Lake Joondalup, and Kingsley, on the eastern bank of Lake Goollelal were opened. By the 1976 census The Wanneroo population had multiplied 6.4 times adding a staggering 46708 people and an additional 12138 dwellings in the space of 5 years. This brought the population of the Wanneroo District to 55328 people occupying 16490 dwellings. (Australian Bureau of Statistics, 1976).

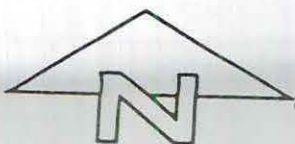
The 1981 census confirms the continuing trend of rapid development. The population increased by a further 38283 people and 11818 dwellings were built. This give a total population for the district of Wanneroo of 93611 people residing in 28308 dwellings. (Australian Bureau of Statistics, 1981) *See Figure 42, p.110.*

LAKE AREA 1973

LEGEND

- URBAN AREA
- OPEN FOREST
Tuat - Jarrah - marri - Banksia
- LIGHT INDUSTRIAL
- SPECIAL RURAL
- JOONDALUP CITY
- SPECIAL RESIDENTIAL
- MAIN ROADS
- PARK BOUNDARY

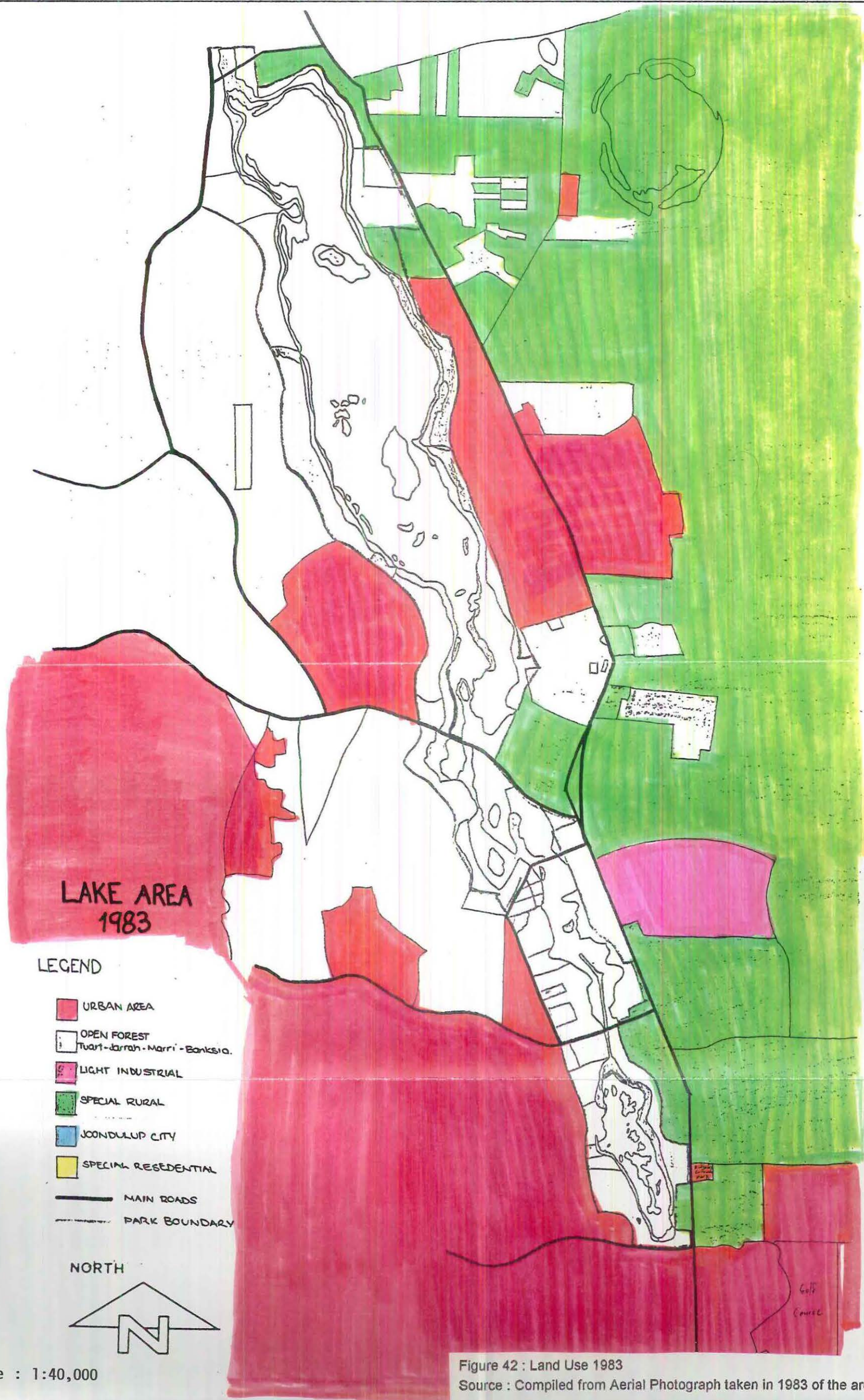
NORTH



Scale : 1:40,000

Figure 41 : Land Use 1973

Source : Compiled from Aerial Photograph taken in 1973 of the area.



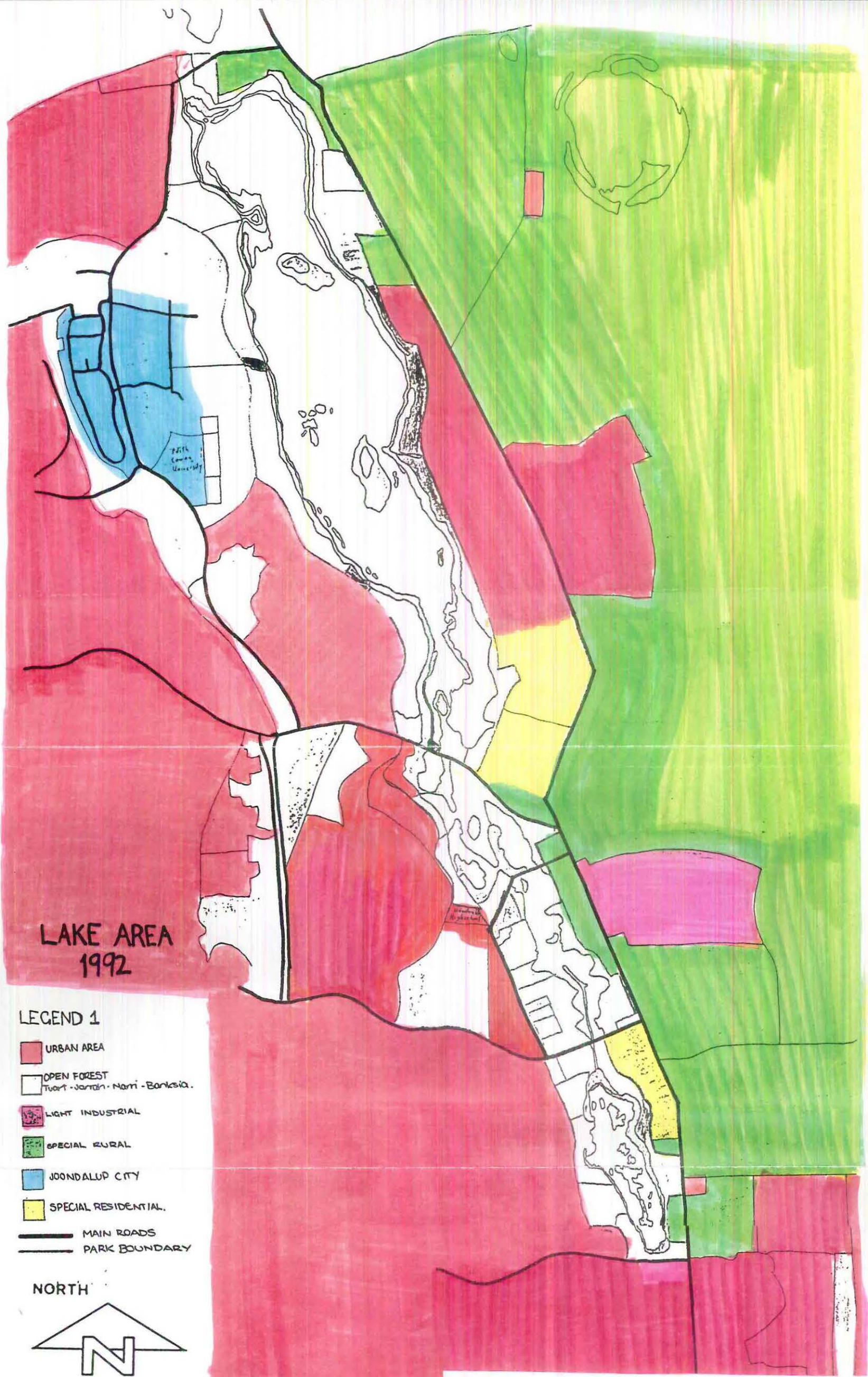
Scale : 1:40,000

Figure 42 : Land Use 1983

Source : Compiled from Aerial Photograph taken in 1983 of the area.

The Woodvale residential subdivision on the western side of Beenyup and Wallubuenup swamps was released in 1984. This is reflected in the 1986 census.—Dwellings had increased by a further 15743 to 44051, and the population had increased by an additional 32442 people to a total of 126053 people. (Australian Bureau of Statistics, 1986) By the middle of the 1980's the area surrounding the lakes was occupied by substantial areas of residential development.

Two subsequent special residential areas were released in 1986: Kingslake on the western side of Lake Goollelal, and Wanneroo Estate on the south-western side of Lake Joondalup. The most recent statistics available are the proposed figures for the 1991 census. The population estimate for the City of Wanneroo is 167,889 people. This represents an additional 41836 people compared with the 1986 census data. (Department of Planning and Urban Development, 1992) This additional development can be seen in *Figure 43, p.112*.

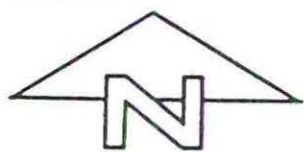


LAKE AREA 1992

LEGEND 1

- URBAN AREA
- OPEN FOREST
Tuart - Jarrah - Marri - Banksia.
- LIGHT INDUSTRIAL
- SPECIAL RURAL
- JOONDALUP CITY
- SPECIAL RESIDENTIAL.
- MAIN ROADS
- PARK BOUNDARY

NORTH



Scale : 1:40,000

Figure 43 : Land Use 1992

Source : Compiled from Aerial Photograph taken in 1992 of the area.

6.5 Current Status

Currently, approximately 1300 hectares of land inside the catchment boundary is developed as residential. As documented in the previous section, this area has significantly increased over the last twenty years. There is also a current proposal for the development of a large Homeswest housing development east of Joondalup. If this development goes ahead it will substantially increase the area within the catchment that is urbanised. The proposed site, Swan Location 2579, Clarkson Avenue, is currently scattered bushland, one of the only large areas of bushland remaining inside the catchment boundary excluding the regional park itself. Residential development of this area is likely to further increase the current affects of urbanisation on the wetland system.

Added to this is the increased development in the Joondalup City Centre. Currently many public and private buildings are under construction and many more are planned. Large areas are also being surfaced with decorative paving, all of which will increase the shedding area of the catchment. Further high density (R40) residential development is also proposed on the western shore of the lake adjacent to the Joondalup City complex.

6.6 Summary of Land Use History

Early settlement of the area in the 1800's appears to have had little or no affect on the water level of the wetlands. There was no introduced water in the system, clearing which results in decreased transpiration was minimal. The lakes water level fluctuated naturally in sympathy with the climate.

The turn of the century brought about little change in this situation. Wanneroo as a rural community consisting of market gardens, poultry farms and dairies had minimal affect on the water level of the wetlands. Although more area was cleared to accommodate these pursuits there was still only a minimal amount of paved area and intensive horticulture was responsible for utilising much of the ground-water that would have been accessed by the original vegetation that

was cleared. A public water supply was not introduced into the area until 1971 when an artesian water supply was introduced. Scheme water was connected in 1976. (Water Authority of Western Australia, 1992, personal communication)

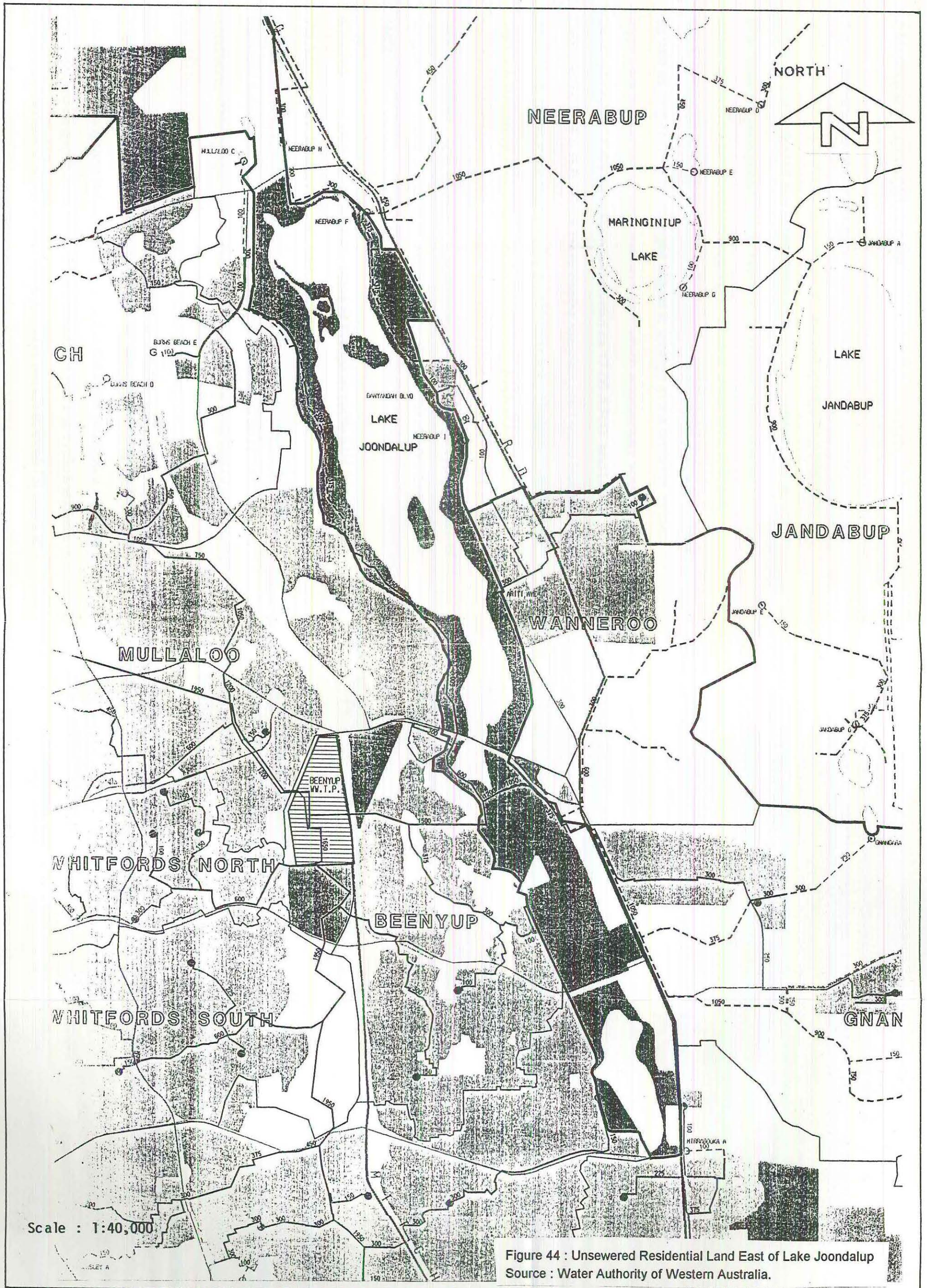
The commencement of large scale residential development in the mid 1970's marks the beginning of the change of this situation. The lake's water balance was no longer exclusively controlled by climatic conditions. It is generally accepted that urbanisation causes increases in the quantity of water recharged locally into the underlying unconfined aquifer, through increased drainage, reduced transpiration and imported water from irrigation and septic tanks. (Gerritse, et al., 1990) In residential areas of Perth, the average recharge to the ground-water is 21% of annual rainfall. (W.A.W.A., 1985)

This recharge in sewered areas amounts to approximately 18 cm, as recharge from watering gardens in summer can be neglected due to high evaporation rates. Therefore, sewered areas are not considered to introduce any significant amounts of water to the system. They do, however, still have the affect of concentrating recharge. Unsewered areas, however, are considered to introduce 17.3 cm annually from septic tanks for a housing density of ten (10) ha⁻¹ (W.A.W.A., 1985) This represents 35 cm total annual recharge, almost double the recharge of sewered areas. (Gerritse, et al., 1990)

Currently there are two main areas within the catchment that are unsewered. The older parts of the Wanneroo town site on the eastern side of Lake Joondalup, which has an approximate housing density of sixteen (16) ha⁻¹ and the new Kingslake Estate on the eastern bank of Lake Goollelal. The later area, however, is zoned special residential, with a housing density of five (5) ha⁻¹. It can, therefore, be concluded that the area of unsewered residential land

east of Lake Joondalup is adding large quantities of water to the wetlands. See *Figure 44, p.116*.

McFarlane, (1984) suggests that the older the sewered area is, the more likely that inputs are to increase due to the leakage of pipes. It is probable, therefore, that these areas will contribute even more water, as well as many pollutants, over time .



CHAPTER 7 : CONCLUSIONS

7.1 Summary of Findings

Information on the water level changes of The Yellagonga Regional Park wetlands was collected and collated through historical research, aerial photography interpretation, Water Authority of Western Australia data and field observation. The data indicates long term cycles of water level changes dependent upon climatic conditions. This pattern of seasonal drying and filling as well as long-term cyclic changes begins to emerge in the historical section. 1838 were the earliest records available from which approximate water levels were calculated. Lake Joondalup is recorded as 17.00 A.H.D. and Lake Goollelal as 26.5 A.H.D. From these depths reconstructed water levels for both lakes have varied more than a metre in each direction. Gregory, (1842, p.27) says of the swampy area bordering on the northern edge of Lake Joondalup, "mud in winter[,] knee deep in dust in summer[,] reed and loose black soil[,] lake and water". This statement supports the conclusion that a cyclic pattern of long term variations of the lakes' water level occurred naturally pre-European settlement.

It can be concluded that in the early years of European settlement in the area, the natural water balance of the lakes' was, except for limited clearing of vegetation, mostly undisturbed by mankind. This water balance fluctuated naturally between high and low water levels as determined by climatic conditions. This apparent natural variation occurred regularly over a cycle of four (4) to six (6) years.

The oral histories produced a similar picture as that uncovered in the historical section. The long term residents suggested that the lakes followed a seasonal cycle as well as a long term cycle. It was suggested that this cyclic trend was of steadily increasing water levels over a period of two (2) to three (3) years to

a peak, followed by a gradual drop in water levels over a period of two (2) or three (3) years when it reached the bottom of the cycle. The process is repeated on a regular basis, as determined by the sequence of wet and dry years.

This pattern of long term seasonal fluctuation of water levels was established by the graphing of water level changes of the lakes. A correlation between water level changes and the climatic data was established in Chapter 5, reinforcing the opinions expressed in the oral history section.

Aerial photographs provided supporting evidence that was used in conjunction with the oral histories. It was not possible however to establish a reliable long term trend as only three (3) photographs were available for the period between 1942-1955.

The long term seasonal trends in water levels of Lake Joondalup and Lake Goollelal were able to be established, although not fully, for the period 1951 to 1968 as data from the Water Authority of Western Australia was sporadic for this period. An accurate reconstruction was possible using Water Authority of Western Australia data for the period 1968 to 1992. This data demonstrated the gradual increase and decrease of the water levels of both lakes over a two (2) or three (3) year period.

A long term variation between the recorded high and low water level of nearly two (2) metres was recorded for Lake Joondalup. Furthermore, it was established with a 95% confidence interval that, in any given year, the water level for Lake Joondalup would fluctuate by between 0.417 and 0.625 of a metre. A long term variation between the recorded high and low water level of 1.107 metres was recorded for Lake Goollelal and it was established with a

95% confidence interval that, in any given year, the water level would fluctuate by between 0.380 and 0.569 of a metre.

The current measurements of the lake levels indicate that Lake Joondalup although high, has been higher in past years. Lake Goollelal, however, has never reached the level that it is currently being recorded at. These measurements also appear to be at the beginning of the upward trend in water levels previously mentioned. It is anticipated that they will be higher next winter.

The fact that Lake Goollelal has reached its highest recorded level this year at the apparent beginning of an upward trend suggests alterations to the water balance not previously experienced. These record high levels appear to be the result of urbanisation after 1975, the affects of which have only become pronounced with the "wet" winters of 1991-1992.

It is concluded that prior to the urbanisation of the areas surrounding the Yellagonga Regional Park there was no substantial human interference with the water balance of the wetlands. The increases in the correlation between climatic data and water levels since the heavy residential development of the catchment zone from 1975, indicates that the development is having the affect of concentrating rainfall within the catchment zone. Presumably increased run-off from paved surfaces is magnifying the affect of individual storm events. More water is therefore reaching the lakes.

Similar to rainfall the correlation between evaporation and lake levels has also substantially increased since urbanisation. The affects of evaporation are more evident during the summer drought period and less significant during the rainy period of May through to October. This means that the evaporation figures

during the summer months are highly correlated but are more poorly correlated during the winter months. This results in the overall correlation between evaporation and water levels being weakened by the winter figures.

It is possible that the increase in correlation between evaporation and water level experienced by the lakes since 1975 is partly due to the heavy urbanisation of the catchment area. Sealed surfaces such as roads and paved areas would contribute to evaporation loss as this water is unable to reach the natural water cycle through seepage into the ground-water system before it is depleted by evaporation. A further reason for this increased correlation could be the decrease evaporation that has been experienced in the Perth area.

The results of this study suggest that the full affects of urbanisation on the lake levels is not experienced until a long term series of wet winters are experienced. For example in Lake Goollelal the last time peak levels were recorded was in 1964 after a series of wet winters.

On the other hand the water levels recorded for Lake Joondalup were still slightly below its highest recorded maximum level (1968) however, the combined affect of the wet winters of 1991 and 1992 may result in the highest Lake Joondalup level on record if this trend of high rainfall continues for the winter of 1993.

The study results may be interpreted to conclude that while the affects of urbanisation coupled with recent trends in rainfall and evaporation have impacted more noticeably on the smaller surface area of Lake Goollelal (122 ha) Lake Joondalup is a much larger body of water (529 ha), and therefore, it is likely that similar affects may be less noticeable in the short term, but are likely to be noticed once this trend is continued over several years. In addition the

affects of urbanisation are likely to be more noticeable in the future in Lake Joondalup with the substantial development that is planned to coincide with the establishment of the Joondalup City Centre. Some of this development will be directed to areas contained within the lakes catchment e.g. Clarkson.

The findings of this study have relevance to numerous aspects of the future management of the Yellagonga Regional Park and its associated wetlands. Lake water levels are central to environmental issues such as eutrophication and the maintenance of productive wildlife habitats. This data is also relevant to the responsibilities of the City Council and the Water Authority of Western Australia for stormwater management. Built structures such as the wooden jetty and the lookout tower at Neil Hawkins Park are presently inaccessible due to the lack of consideration of water level fluctuations in the location of these facilities. There is clearly a need for any future management plan for this area to consider water level and climatic data and the potential affect of land-use changes. However, as demonstrated in this study, the full affect of land-use change may not be discernible for a number of years.

BIBLIOGRAPHY

- Allen, A. D. (1976). The swan coastal plain - hydro geology of superficial formations. In: B. A. Carbon (Ed.), Ground water resources of the swan coastal plain. (pp.12-33), Perth: C.S.I.R.O. Division of Land Resources Management.
- Allen, A. D. (1980). The hydrogeology of Lake Jandabup, swan coastal plain, Western Australia Geol. Surv. Ann. Report. 30-40.
- Allen, A. D. (1981). Ground water resources of the swan coastal plain, near Perth, Western Australia. In: Ground water resources of the swan coastal plain pp. 29-72, Perth: C.S.I.R.O. Division of Land Resources Management.
- Allen, R. (1975). Saving wetlands for a rainy day. New Scientist, 18/25, 703 - 705.
- Aplin, T. E. H. (1977). Report of the algae odour control working group. Perth: Dept. of Conservation and Environment.
- Armstrong, P. H. (1975). The changing landscape. Lavenham: Terence Dalton.
- Arnell, V. (1982). Estimating runoff volumes from urban areas. Water Resource Bulletin 18, 383-387.
- Arnold, J. & Wallis, R. (1985). Assessment of metropolitan wetlands - a method. Paper presented at 24th Australian Society for Limnology Congress Perth W.A.
- Arnold, J. M. & Wallis, R. L. (1987). Wetlands : a consideration in the development of the unconfined groundwater systems underlining Perth, W.A. Proceedings of the International Conference on Groundwater Systems Under Stress. Australian Water Reserve Council, No. 13, Australian Government Publishing Service.
- Atkins, R. & Humphries, B. (1988). Catchment management and in-lake solutions. Environmental Protection Authority. Bulletin 372, p.72-82.
- Atkinson, A. (1984). Chinese market gardening in the Perth metropolitan region, 1900-1920. West. Geogr. 8, 38-52.
- Australian Bureau of Statistics (1954). Census of Population and Housing, Western Australia.. Perth: Australian Bureau of Statistics.
- Australian Bureau of Statistics (1961). Census of Population and Housing, Western Australia. Perth: Australian Bureau of Statistics.
- Australian Bureau of Statistics (1966). Census of Population and Housing, Western Australia. Perth: Australian Bureau of Statistics.
- Australian Bureau of Statistics (1971). Census of Population and Housing, Western Australia. Perth: Australian Bureau of Statistics.
- Australian Bureau of Statistics (1976). Census of Population and Housing, Western Australia. Perth: Australian Bureau of Statistics.

- Australian Bureau of Statistics (1981). Census of Population and Housing, Western Australia, Perth: Australian Bureau of Statistics.
- Australian Bureau of Statistics (1986). Census of Population and Housing, Western Australia, Perth: Australian Bureau of Statistics.
- Australian Water Resources Council (1975). A descriptive catalogue of the Australian representative basins. Canberra: Australian Government Publishing Service.
- Australian Water Resources Council (1991). An AWRC Strategy for Water Quality Management. A discussion paper, March 1991.
- Ayre, D., Colreavy, M., Coster, P., Fisher, K., Hill, A., Lymbery, A., McShane, P. & Threlfall, T. (1977). A limnological survey of Lakes Jandabup, Joondalup and Loch McNess. Group Project for B.Sc. (Hons.), Dept. of Zoology, University of W.A. Nedlands.
- Bayly, D. A. E. & Williams, W. D. (1973). Inland waters and their ecology. Australia: Longman.
- Bekle, H. (1979). A seasonal biogeography of Lake Joondalup. B.A. (Hons.) thesis, Dept. of Geography, University of W.A., Nedlands.
- Bekle, H. (1980). A seasonal biogeography of Lake Joondalup. Geowest, 16, 83-119.
- Bekle, H. (1981a). The wetlands lost : drainage of the Perth lake systems. West. Geogr. 5, 21-41.
- Bekle, H. (1981b). The ecological interpretation of historical data : a case study of selected wetlands in the Perth metropolitan region. Paper presented at 51st A.N.Z.A.A.S. Congress (Brisbane), May 1981.
- Bekle, H. (1984). A comparative review of lakes in the Perth metropolitan area. West. Geogr. 8, 61-77.
- Bekle, H. (1988). Waterbird Usage of Lakes in The Perth Region Western Australia : a study of pattern in time and space. Unpublished Doctoral Dissertation, U.W.A. Perth, W.A.
- Bowman, M., Chambers, M., Dunlop, N., Hart, L., Hogan, T., Lievense, D., & Maisey, K. (1976). The Cockburn wetlands - an environmental study. A report prepared by Murdoch University, W.A. (unpublished).
- Briggs, S. V. (1976). Comparative ecology of four new England wetlands. Master of Natural Resources Thesis, University of New England, Armidale.
- Bureau of Meteorology, (n.d.) (Leaflet), Guidelines for the siting and exposure of meteorological instruments and observing facilities. (Available from the Bureau of Meteorology, Perth).
- Butler, J. (1834). Exploration Diaries Vol. 2 1834-1835.
- Cameron, J. M. R. (1975). The colonisation of pre-convict Western Australia. Unpublished Doctoral Dissertation, University of W.A. Nedlands.

- Carbon, B. A. (ed.) (1976). Groundwater resources of the Swan coastal plain. Perth: C.S.I.R.O., Division of Land Resources Management
- Carbon, B. A. Bartle, G. A. & Murray A. M. (1988) Some basic information for the management of urban lakes near Perth, Western Australia. Perth: C.S.I.R.O., Division of Water Resources.
- Cargeeg, G. C., Boughton, G. N. Townley, L. R., Smith, G. R. Appleyard, S. J. & Smith, R. A., (1987). Perth Urban Water Balance Study, Volume : 1, Findings. Water Authority of Western Australia, Leederville.
- Chambers, A. (1991). The Pioneers, A Story of Wanneroo 1834-1985. The Shire of Wanneroo. Western Australia.
- Chauncey, P. S. (1842). Field Book Number 14.
- Chauncey, P. S. (1844). Field Book Number 13.
- Clay, P. A. (1976). Field study of Thompson Lake reserve : January 1976 to June 1976. Unpublished report prepared for W.A. Dept. of Fisheries and Wildlife, Perth.
- Coffey, P. (1990). Report on an Investigation into Scientific and Educational Values of Wetlands and Rivers in the Perth-Bunbury Region. Perth: Western Australian Water Resources Council.
- Congdon, R. A. (1973). Studies on the synecology of Lake Joondalup, Western Australia and the autecology of juncus species. B.Sc. (Hons.) thesis, Dept. of Botany, University of W.A., Nedlands.
- Congdon, R. A. (1979). Hydrology nutrient loading and phytoplankton in Lake Joondalup : A feasibility study. W.A. Dept. of Conservation and Environment, Bulletin, 183.
- Congdon, R. A. (1985). The water balance of Lake Joondalup. W.A. Dept. of Conservation and Environment, Bulletin, 183.
- Congdon, R. A. (1986). Nutrient loading and phytoplankton blooms in Lake Joondalup, Wanneroo, Western Australia. Perth: Technical Series No. 6, Department of Conservation and Environment.
- Congdon, R. A. (in press) Spatial and temporal changes in physical and chemical aspects of Lake Joondalup. Perth: W.A. Environmental Protection Authority.
- Congdon, R. A. & McComb, A. J. (1976). The nutrients and plants of Lake Joondalup, a mildly eutrophic lake experiencing large seasonal changes in volume. J. Roy. Soc. West. Aust. 59 (1), 14-23.
- Corrick, A. H. & Cowling, S. J. (1975). A survey of the wetlands of Kerang, Victoria. Fish Wildl. Pap., Vict. No. 5.
- Corrick, A. H. & Norman, J. I. (1980). Wetlands of Victoria. I. Wetlands and waterbirds of the Snowy river and Gippsland lakes catchment. Proc. R. Soc. Vict. 91, 1-15.
- Cowle, J. (1867). Field Book No. 2.

- Cowle, J. (1872). Field Book No. 6.
- C.S.I.R.O. (1976). Landforms and soils of the Perth metropolitan north-west corridor - Western Australia. Perth: Division of Land Resources Management, C.S.I.R.O.
- Cullen, P. W. & Rosich, R. S. (1980). Managing urban lakes. In Williams, W. D. (Ed.), A biological basis for Australian resource management. ANU Press.
- Cullen, P. W. (1990). Wetlands and urban stormwater. Adelaide: Australian Water and Wastewater Association.
- Dames, & Moore (1986a) Gnangara mound groundwater resources : environmental review and management programme. Water Authority of Western Australian
- Dames, & Moore (1986b) Gnangara mound groundwater resources : environmental review and management programme. Appendices. Water Authority of Western Australian
- Daniel & Cockman, M. (1979). The Wanneroo Story. Perth: City of Wanneroo.
- Davis, J. A. & Humphries, B. (1988, June), Wetland Function. Environmental Protection Authority, Bulletin 372, p.52-62.
- Davis, J. A. & Rolls, S. W. (1987). The role of odonata, and aquatic coleoptera as indicators of environmental quality in wetlands. In: J. D. Majer (ed.), The role of invertebrates in conservation and biological survey. Proc. 18th Scientific Conference of the Australian Entomological Society, Perth, pp.31-42.
- Davis, J. A. & Rolls, S. W. (1987). A baseline biological monitoring programme for the urban wetlands of the swan coastal plain, Western Australia. W.A. Environmental Protection Authority, Bulletin. 265.
- Davis, J. A. & Rolls, S. W. & Wrigley, T. J.. (1991). A Survey of the Environmental Quality of Wetlands on the Gnangara Mound, Western Australia. Perth: Water Authority of Western Australia and Environmental Protection Authority. Report No. WG 113.
- Department of Conservation and Environment (1977). Guidelines to the conservation and management of wetlands in Western Australia. Department of Conservation and Environment. Perth, Western Australia.
- Department of Conservation and Environment (1980). Wetlands : guidelines for protection and management. W.A. Dept. of Conservation and Environment, Bulletin. 79.
- Department of Conservation and Environment (1981). The Darling System Western Australia - Proposals for Parks and Reserves. System 6 Study Report to the E.P.A. W.A. Dept. of Conservation and Environment, Rept. No. 8.
- Department of Conservation and Environment (1986). Draft guidelines for wetland conservation in the Perth metropolitan area : report and

recommendations by the Environmental Protection Authority. W.A. Dept. of Conservation and Environment, Bulletin. 227.

Department of Land Administration, (1986a). Map Sheet Perth N/W..

Department of Land Administration, (1986b). Map Sheet Muchea SW.

Department of Lands and Surveys. (1869). Swan 35. Swan Location - Goolelal.

Department of Lands and Surveys. (1842). Swan 35a. Swan Locationa - Gngarra.

Department of Lands and Surveys. (n.d.). Swan 37. Swan Location - Joondalup.

Department of Lands and Surveys. (1842). Swan 48. Swan Location - Lakes North of Perth.

Department of Lands and Surveys. (1842). Swan 55. Swan Location - Lakes North of Perth.

Department of Lands and Surveys. (1884). Swan 136. Swan Location - Vicinity of Lakes Jandabup, Joondalup, Gngarra and Coollelal.

Department of Lands and Surveys. (n.d.). Swan 137 - Swan Location Vicinity of Lakes Jandabup, Marijiniup, Joondalup.

Department of Lands and Surveys. (1903). Swan 270 - Swan Location Vicinity of Marmion townsite and Wanneroo Road.

Department of Lands and Surveys (1929). Perth Map L.O. 1/A.

Department of Planning and Urban Development, (1992). Resident Population and Projected Population, Perth Statistical Division, Perth: Department of Planning and Urban Development.

Drummond, J. (1840). Letters on vegetation of swan coastal plain and scarp and of Rottnest Island. J. of Bot. 2, 343-371.

Environmental Protection Authority (1986). Draft guidelines for wetland conservation in the Perth metropolitan area. Perth: W.A. Dept. of Conservation and Environment.

Environmental Protection Authority (1987). Gngarra mound groundwater resources. Environmental Protection Authority and The Water Authority of Western Australia, Bulletin 295.

Environmental Portection Authority (1989). Wetlands in Crisis. What can Local Government Do? Perth: EPA. Bulletin 372.

Environmental Protection Authority (1990). Jenny Arnold's Perth wetland resource book, Chapter 7 Wanneroo linear lakes. Environmental Protection Authority and The Water Authority of Western Australia, Bulletin 266.

- Erickson, R. (1964). History of the Western Australian Naturalists' Club. W.A. Natur. 9 : 121-152.
- Evans & Sherlock, (1950). Butler's Swamp. W.A. Naturalist 2 : 152-160.
- Fraser, M. A. C. (1902-4). The Western Australian official year book. Perth: Government Statistician.
- Froend, R. (1990). . Vegetation Survey Yellagonga Regional Park. (unpublished).
- Gause, G. F. (1934). The struggle for existence. Baltimore: Williams and Wilkins.
- Gentilli, J. (1972). Australian climate patterns. Melbourne: Nelson.
- Gentilli, J. (ed.) (1979a). Western landscapes. Nedlands: University of W.A. Press.
- Gentilli, J. & Fairbridge, R. (1951). Physiographic diagram of Australia. New York: Geographical Press, Colombia University.
- Gentilli, J. & Rumley, D. (1977). A bibliography of metropolitan Perth. Geowest, 10.
- Gerritsi, R. G., Barber C. & Adeney J. A., (1990). The Impact of Residential Urban Areas on Groundwater Quality: Swan Coastal Plain, Western Australia. Perth: C.S.I.R.O. Water Resources Series No.3.
- Godfrey, N. (1988). The value of wetlands. Environmental Protection Authority, Bulletin 372, p.4-12.
- Goodrick, G. N. (1970). A survey of wetlands of coastal New South Wales. C.S.I.R.O. Div. Wildl. Res. Tech. Memo.
- Gregory, A. C. (1842) Field Book No. 2.
- Grey, G. (1841). Journals of two expeditions of discovery 1837 - 1839 (2 volumes), London.:Boone.
- Halse, S. A. & Ward, D. (1987). Assessing conservation value of wetlands. Aust. Soc. for limnology Newsletter, 25 (3) p. 36
- Hancock, D. (1979). The westerners. Bay Books, Rushcutters Bay.
- Happs J. C. (1978). Water Pollution and its Measurement. Perth: The Jacaranda Press.
- Hart, L. A. (1978). Wetland ecosystems : a study of several swan coastal plain wetlands with implications for management. B.Sc.Env. Sci. (Hons.) thesis, Murdoch University, Western Australia.
- Honey, F. R., Hick, P. T. & Blatchford, D. R. Level inventory on monitoring of wetlands on the swan coastal plain of Western Australia. In Proc. XII Int. Symp. on remote sensing of the environment. Michigan: Environmental Research Institute of Michigan.

- Humphries, R., Bott, G., Deeley, D & McAlpine, K. (1989). The relationship between wetlands and groundwater. In G. Lowe (Ed.), Swan coastal Plain groundwater management conference - proceedings (pp.113-119). Perth, Western Australia : Western Australian Water Resource Council.
- Jaensch, R. P. (1986). A reconnaissance of north-eastern wetlands in Western Australia. W.A. Bird Notes 38, 6-7.
- Jarvis, B. D. (1991). Lake Joondalup - Stormwater Disposal Management Strategies. Perth: City of Wanneroo.
- Jutson, J. (1934). The physiography of Western Australia. W.A. Geol. Surv. Bulletin. 95 : 46
- Lane, J. A. K. & McComb, A.J. (1988). Western Australian wetlands. In: McComb, A. J. & Lake, P. S. (eds.) (1988). The conservation of Australian wetlands. N.S.W.: Surrey Beatty and Sons Pty Ltd.
- Lane, J. A. K. & Munro, D. R. (1981). 1980 Review of rainfall and wetlands in the south-west of Western Australia. W.A. Dept. Fish and Wildl. Rept. 47.
- Layton Groundwater Consultants (1976). The lakes regional open space hydrological and geological study for the Shire of Rockingham. Layton Groundwater Consultants, Western Australia.
- LeProvost, Semeniuk & Chalmer, (1987) Environmental Significance of Wetlands in the Perth to Bunbury Region. Perth: Western Australian Water Resources Council.
- Lowe, G. (1989, January). Swan Coast Plain Groundwater Management Conference. Paper presented at the Alexander Library Perth for the Western Australian Water Resource Council. Perth, W.A.
- McArthur, W. M. & Bartle, G. A. (1976). Landforms and soils of the Perth metropolitan north-west corridor - Western Australia. Perth: Division of Land Resources Management, C.S.I.R.O.
- McArthur, W. M. & Bettenay, E. (1960). The development and distribution of soils of the Swan Coastal Plain, Western Australia. C.S.R.I.O. Aust. Soil. Publ. 16
- McComb, A. J. & Lake, P. S. (eds.) (1988). The conservation of Australian wetlands. N.S.W. : Surrey Beatty and Sons Pty Ltd.
- McFarlane, D. J. (1984). The effect of urbanisation on groundwater quantity and quality in Perth, Western Australia. Unpublished Honour's Thesis, Geology Department, University of Western Australia., Perth.
- Metropolitan Region Planning Authority (1976). Herdsmen Lake - Concept Plan. Perth: M.R.P.A.
- Moore, G. F. (1884). A descriptive vocabulary of the language in common use amongst the Aborigines of Western Australia : with copious meanings embodying much interesting information regarding the habitats.

- manners and customs of the natives and the natural history of the country. London.: First printed 1842, Williams, S. Orr and Co.
- Nicholson, E. M. (1958). Past present and future. In: G. Mountfort, (Ed.), Portrait of a wilderness, chap. 18, (pp.203-215). London.: Hutchinson.
- O'Connor, R., Quartermaine, G., & Bodney, C., (1989). Report on a survey for aboriginal sites in the vicinity of Lake Joondalup, Perth.: Western Australian Water Resource Council.
- Office of Survey General, (1890). Public Plan C1 and C4.
- Pitt Morison, M. (1979). Settlement and development : historical context. Chapter 1 in : Pitt Morison, M. & White, J. (eds) 1979. Western towns and buildings. Nedlands: University of W.A. Press, pp.1-73.
- Playford, P. E., Cockbain, A. E. & Low, G. W. (1976). Geology of the Perth basin. W.A. Geol. Surv. Bulletin. 124
- Quinn, R. (1862). Field Book No. 4.
- Riggert, T. L. (1966). A study of the wetlands of the Swan Coastal Plain. Perth.: W.A. Dept. Fish. and Fauna.
- Row, S. (1839). Field Book 1.
- Ruscoe, R. (1977). Unpublished report, City of Wanneroo : Perth, Western Australia.
- Saw, W. A. (1884). Field Book No.4.
- Scott, D. R. (1979). Evolution of a landscape - manufacturing. In: Gentilli, J. (ed.) Western Landscapes, plates 21.1 and 21.2, Nedlands: University of W.A. Press.
- Seddon, G. (1972). Sence of place. Nedlands: University of W.A. Press.
- Serventy, D. L. (1948). The birds of the Swan River district, Western Australia, Emu 47, 241-286.
- Serventy, D. L. (1972). Fauna of coastal plain swamps. In Seddon, G. (1972), Sence of place - a responce to an environment: The swan coastal plain, Western Australia, Nedlands.: University of W.A. Press.
- Shire of Wanneroo. (1933). Map of the Wanneroo Shire, unpublished, Shire of Wanneroo : Perth, Western Australia
- Singleton, J. (1988). The history and tenure of wetlands. Environmental Protection Authority, Bulletin 372, p.13-50.
- Smith, D. I. (1986). Australian water resources: problems, policies and catchment. Centre for Resource and Environmental Studies, The Australian National University.
- Smith G. G. (1973). A guide to the coastal flora of South-Western Australia. W.A. Naturalist's Club, Handbook No. 10, Perth.

- Smith, G.G. (1980). Rushes, sedges and reeds. W.A. Natur. 14 : 169-174.
- Smith G. G. (1987). Perth urban water balance study Vol 1 findings. Water Authority of W.A. Perth. Ch 7 "Perth urban water balance with possible future management practices." Perth.: Water Authority of W.A.
- Smith, G. G. & Marchant, N. C. (1961). A census of aquatic plants of Western Australia. W.A. Natur. 8 : 5-17.
- Southern, B. L. & Teakle, L. J. H. (1937), A soil survey of Herdman Lake, J Dept. of Agric. W.A. 14, 404-424.
- Stephenson, G. (1977). Joondalup regional centre. Nedlands.: University of W.A. Press.
- Tyman, J. L. (1976). Surveys and settlement in Western Australia. Geowest 9
- Ventriss, H. (1988). Management of water resources. Environmental Protection Authority, Bulletin 372, p.66-71.
- Walsh, D. (1991). Eutrophication of Hazelmere Lakes - investigation of nutrient inputs from stormwater run-off. Unpublished report, Shire of Swan : Perth, Western Australia
- Watson, T.(1834) Exploration diaries Vol 2 1834 - 1835.
- Western Australian Department of Fisheries and Wildlife (1978). Wetlands of South-Western Australia with special reference to the Busselton Area. W.A. Dept. Fish. and Wildlife. Special Publication.
- Western Australian Museum (1978). Faunal studies of the northern swan coastal plain : A consideration of past and future changes. Perth.: A report prepared for the Western Australian Department of Conservation and Environment.
- Western Australian Water Authority, (1985). Domestic Water Use in Perth, Western Australia. Unpublished report, W.A.W.A. : Perth.
- Western Australian Water Resource Council, (1988). Swan Coastal Plain groundwater management conference. Western Australian Water Resource Council.
- Western Australian Water Resource Council, (1989) Groundwater resource assessment in Western Australian a strategy for the future. Western Australian Water Resource Council
- Wetlands Advisory Committee (1977). The status of wetland reserves in System 6. Perth: Unpublished report of the Wetlands Advisory Committee to the Environmental Protection Authority.
- Whittaker, R. H. (1975). Communities and ecosystems. New York: Macmillan.